INFLUENCES ON DEVELOPMENT AND INNOVATION IN EDUCATIONAL TECHNOLOGY

by

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Influences on Development and Innovation in Educational Technology

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Executive Summary

This report is part of a study, "Educational Technology: An Assessment of Practice and Potential," commissioned by the House Committee on Education and Labor to the Office of Technology Assessment. In this report, as professionals who develop both customized and commercial educational technology products, we:

- Provide a look at the history of educational technology, including both successful and unsuccessful government and private enterprise projects, during the past three decades;

- Examine trends in technological factors and new technologies that will influence development of innovative educational hardware and software during the next five years;

- Develop a set of policy options for strategic federal support that can maximize the gains of past development efforts, and can encourage the greatest benefits from future federal, state, and private initiatives.

Our approach is, by design and necessity, a synoptic one. Our involvement in modern educational technology research and development, and in the hardware and software development that preceded it, spans the past 25 years. We have synthesized previous surveys, and have made considerable use of personal experience, anecdotal information, and well-documented sources, both published and unpublished. In addition, we have conducted informal interviews with a wide variety of academic and industrial researchers, educational technology developers, curriculum developers, publishers, teachers, and training specialists.

We illustrate trends and factors influencing innovation in educational technology development via several brief, descriptive examples of development projects. We have given special attention to spinoffs or "side effects" -- many originally funded by the military during the 1960's-- particularly spinoffs from projects whose original focus was not on education *per se*. The general educational community and the public are just beginning to appreciate the history, outcomes, and wide-ranging impacts of these spinoffs. In this report, we stress the importance of systematically seeking models for innovation in educational technology outside the schools, as well as in the traditional K-12 classroom.

In our retrospective and "update" on educational technology development, we have concentrated on three "focus areas."

- Research on extending and improving the human-machine interface;
- "Authoring" tools and algorithms for interactive media;
- Models, design criteria, and standards for developing exemplary educational software.

These areas provide conceptual "threads" for relating past and present R&D efforts to future innovation in educational technology.

We have summarized our experience as developers and the results of our research studies into ten trends that affect the development of new educational technology applications and products. Understanding these trends can provide major opportunities for innovation in expanding "lifelong learning" in all sectors of society, in this country and abroad.

We recommend the following areas as major opportunities for federal support of innovation in educational technology:

- Creation and support of a national network of interdisciplinary "Educational Technology Centers of Excellence," focused on applying cognitive science and related educational technology R&D to improving both formal and informal education;

- Integration of educational technology components into successful previous curriculum development and teacher-training efforts;

- Basic and applied research in the areas of the psychology of intrinsic motivation, self-esteem, and the influence of personality and social factors of the learner, as well as understanding the nature of the interactive teaching-learning process;

- Cooperative industry/government/university-supported programs for training of teachers and other professionals involved in the development and implementation of educational technology;

- Continuous development and dissemination of models, standards and criteria for exemplary educational technology, matched to both current standards of teacher accountability and to future development of new methods of assessment and evaluation of excellence in teaching and effective learning.

Our recommendations for federal policy, posed as options for stable, long-term support, should be viewed as "strategic investments." They reflect our effort to maximize the gains from the major investments made in support of development of both computer-based technologies and innovative curricula during the past three decades.

We recommend a national "action research" agenda for applying the results of these efforts to solving the current problems of the schools. However, we believe that this agenda cannot be effective without expanding the focus of educational technology from the K-12 classroom to lifelong learning. Educational technology impacts all who are part of a "learning society," one which must encourage maximum opportunities for lifelong education and self-renewal for learners of all ages, abilities, and backgrounds.

Introduction

During the past thirty years, educational technology has made enormous progress in providing new learning opportunities for people of all ages and backgrounds. Powerful communications media, including books, radio, film, television, audio, and video, may be seen as "vehicles" for enhancing teaching and learning. Of all of the developments in educational media during the past two decades, the most important single advance has been the development of the microcomputer, a medium capable of amplifying and enriching all other media.

Microcomputer chips are not limited to computers. They appear in our cars, washing machines, toys, games, cameras, ovens, audio, and video systems. The power and widespread influence of this technology are evidenced by the fact that microcomputer components are at the heart of the most advanced learning systems used today in business, industry, military and government training, schools, libraries, and museums. Personal computers are indeed ubiquitous.

The importance of microcomputer-based educational technology may be summarized in one word: interactivity. Microcomputers are the first widely available, general purpose, programmable interactive media for learning. The element of interactivity is at the heart of education. Since long before Socrates' time, good teachers have recognized the importance of dialogue in imparting, clarifying, and exploring knowledge. Now, with the availability of interactive media, good teaching may be multiplied and facilitated in all learning environments, from the classroom to the home.

Interactive media are unique in that they can be made responsive to the user's ideas and control through thoughtful design and programming. Consequently, the development of technological devices (hardware) has resulted in a concomitant multi-billion-dollar industry in the development of software, the programs that allow general-purpose microcomputers to be applied to a vast variety of needs and desires. In educational applications, such software is known by a variety of names: Computer

Assisted Instruction (CAI), Instructional Courseware, Computer-Based Training (CBT), Computer Managed Instruction (CMI), Interactive Training, and Intelligent Tutoring Systems (ITS).

Development of effective interactive media for learning and teaching requires a comprehensive understanding of the learner -- his or her previous experiences, needs, styles of thought, models, expectations, and motivations -- a totality which has been called "mindware" (Salomon, 1985). At the same time, developers must couple this understanding of the learner with a deep understanding of content and pedagogy -- e.g., how best to teach the laws of physics, or how best to teach the communication skills required for effective sales. This knowledge of the teaching and learning process must then be matched to the art of combining the ideal blend of characteristics embodied in both hardware and software media to enhance and enrich the educational experience, whether it be for a young child or a highly trained professional.

Interactive educational technology poses unique challenges for designers and developers. Since these media are molded by their content ("programming"), designers and developers must help students, teachers, and authors gain an easy command of their environment. Consequently, as educational technology has become cheaper and more powerful, a steadily increasing focus has occurred in psychology, engineering, and industrial design on "human factors" -- that is, how to give users of these devices maximum flexibility with a minimum of training, effort, or interference.

The bridge or "handshake" between the user, the software, the computer, and the computer's peripheral devices is called the "human-machine interface." It is a rich area of interdisciplinary research that has grown considerably since its pioneering days during World War II, and it will continue to be active for many years to come (Norman & Draper, 1987; Foley, 1987; Bolt, 1984). In our opinion, the human-machine interface is also one of three realms in which the greatest payoffs in educational technology R&D will continue to occur.

Our study began with a survey of several excellent assessments of the trends and potential for innovation in education and educational technology, both current ones (Leonard, 1987; Johnston, 1987, 1985; Lawler, 1986; Greenfield, 1984; Licklider, 1984) and past summaries (Brown, et al., 1973; Oettinger & Marks, 1969). These resources provided the foundation for this report, and they summarize many of the forces which both encourage and inhibit innovative use of interactive media in education, both from a historical perspective and in today's schools.

However, this particular study examines these same issues from the unique perspective of the developer. Developers of educational technology include: teachers, cognitive scientists, instructional designers, graphic artists, media specialists, engineers, manufacturers, school administrators, investors, and business people. Our report explains what developers do, traces how they have designed and produced interactive learning materials during the past three decades, and provides examples and trends regarding high-quality microcomputer-based products.

Our main goal is to illuminate the forces promoting and inhibiting innovation in this field, and to define the issues developers face in attempting to maximize the potential of these powerful media for improving education. In this report, we document some of these problems and opportunities, focusing on the developers themselves, the environments in which development takes place, and the technology and tools developers use. We examine several different development environments, from a public high school to the sales training department of a Fortune-500 research & development company. These examples illuminate some of the factors and trends that encourage and discourage innovation in educational technology research and development. In discussing these environments, we give special attention to the importance of individual people in the development process. We have spoken to a wide variety of people who are actively involved in the field, including private sector developers, university and museum educators and researchers, educational product marketing executives, corporate training specialists, and school teachers.

In the spirit of John Naisbitt (1982), we have identified ten "megatrends" in educational technology. These trends reflect great promise for mass improvement in formal and informal education, and ultimately will result in the augmentation of an even wider range of human activities in the worlds of work and leisure. The trends include:

- Increasing mass availability of smaller, faster microcomputers and systems as integral parts of consumer devices and products designed to augment the full spectrum of human activities.

- Development of new hardware and software that extends the concepts of "input" and "output." Input is extended from one student typing at a keyboard to full-body input or to a global community of learners and teachers. Output is extended from letters and numbers on a TV screen to a vast range of visual images and multiple media, all easily accessible in a common digital form.

- Maturation of design tools and authoring tools. Using these tools, developers will be able to create high-quality, low-cost, interactive, multi-media learning materials more effectively. These tools will also help teachers, parents, students, and researchers to become more deeply involved in the development process.

- Advances in cognitive science, social and environmental psychology, and interdisciplinary approaches to research that are now being applied to education, and the expansion of the concept of education from the formal classroom to the workplace and informal (leisure) environments.

In summarizing our conclusions and recommending policy options, we are heavily biased toward quality, durability, invariants, and long-term trends, rather than toward any particular device or innovation. We conclude that the roots of innovation are perceived by few people at the time of their inception or early development, and that the propagation of such innovation depends both on increasing public awareness and on the *zeitgeist*. In addition, we believe many of the most important advances in educational technology have come from "spinoffs" of projects outside of education *per se*, especially in the development of effective human interfaces to new technology. Finally, the success of these innovations is determined by individual commitment and human creativity from all those involved in development -- teachers, researchers, hardware manufacturers, software designers, publishers, and funding sources. Implementing long-lasting change using new educational technologies will only come about from a patient, long-term commitment to the priority of excellence in education.

Context

This study addresses the need for educators, business people, and the government to understand what the new technologies can do and how to best use them for productive, lifelong learning. Its focus lies on an extrapolation of historical trends from a developer's perspective -- what is to be expected and where the best opportunities lie for innovation and long-term impact in the near-future. Three explicit tasks are addressed:

- A three-decade retrospective on successful and unsuccessful product development is presented.
- Technological factors, as they influence educational software and hardware, are projected for the next five years and ten trends are enumerated.
- A set of policy options, which can be used by developers to place various programs and actions in perspective, is offered.

In addressing these tasks, we have focused on three particular aspects of the development process which we feel require special attention:

- Continued research into improving and extending the human-machine interface;

- "Authoring" of interactive learning materials (with a focus on tools for non-programmers and developing effective teaching "algorithms");

- Evolution of models, criteria, and standards for design of exemplary educational software.

Innovation and the Process of Development

> "...the capacity of society for continuous renewal depends ultimately on the individual. He is the seedbed of change, the inventor and innovator, the critic of old ways and the mapper of new paths."
>
> -- John W. Gardner (1963)

Who are the developers of interactive media and what do they do? What is involved in making innovative contributions to educational technology research and development?

The development of educational technology products (both hardware and software) involves many different people, from authors and teachers to publishers and business people. Some products have been conceptualized, designed, implemented, and marketed by a single individual in the space of a few weeks, while others have involved interdisciplinary design teams (some of whom may be separated by thousands of miles), working over a period of years. The common thread is an interest in improving education through productive use of appropriate media and other available resources.

Educational technology now encompasses many more media and actors in the development process than those previously involved in writing and publishing books. Recent advances in hardware, software (e.g., "desktop publishing"), and cognitive science have now resulted in an even wider expansion the universe of people involved in the development process. Perhaps most importantly, developers and consumers of educational technology should no longer view the computer in isolation from other technologies. Other media--such as digital audio, videotape and videodisk, mass optical storage (CD-ROM), telecommunications networks, and television--are already widely accepted as portions of computer-mediated, interactive, multi-media learning products for military and corporate training applications (Wolman, 1987), and schools are not far behind (Apple, 1987). Current and future educational systems can and will make use of these as components of fluidly changing configurations, ultimately weaving a "seamless carpet of knowledge and learning" (Ofiesh, 1986).

It is the open-endedness of these multi-media combinations that gives such an immense stimulus to developers today. We shall take here the technology to embrace not only hardware and software, but also authoring tools, programming languages, teaching algorithms, and the psychology of learning and thinking. When all of these factors are viewed together by the developer as components of the complete learning system, they influence and condition the way in which optimal effects can be achieved.

The ultimate criterion of good technology is invisibility. With a skillfully designed machine, the user need only be aware of the functions that are needed at the moment for control. Everyday examples can serve as guidelines, such as: the elevator, sailboat, car, video cassette recorder, stereo system and compact disk player, telephone, and television. The designer's goal is to make technology serve unobtrusively. Consequently, the primary measure of the impact of a technology is taken by removing it and examining the vacuum that is left behind. For example, take books out of the schoolroom and see how it goes. Or take away the Public Broadcasting System to gauge its value.

From the developer's point of view, it is useful to view all of educational technology as a medium for communication, having these components:

- **Content:** Subject matter: information, skills, processes;

- **Equipment:** The physical media themselves (hardware);

- **"Programming":** Creating, structuring, modifying content (software), and algorithms for effective teaching;

- **Support Materials:** Videotapes, workbooks and activity sheets, teachers' guides and manuals, manipulatives, and other "hands-on" materials;

- **People:** Students, teachers, authors, designers, artists -- human beings who in one way or another are involved in the process, both as developers and as consumers;

- **Learning Environment**: Both the physical space (classroom, home, museum, library, etc.) and psychological contexts of learning (goals, objectives, expectations, teaching and learning philosophy, attitudes, etc.)

Almost all of these elements hold true for both one-way technologies (most print media, educational television, self-study audio and video tapes, etc.) and interactive technologies (e.g., microcomputers, interactive video, two-way cable TV). However, as stated above, interactive computer-based technologies have a unique set of design constraints, and it is this particular educational technology on which we will focus our attention in this report.

The Four Faces of Interactive Teaching-Learning Machines

With interactive educational technology, the learner and the media form an intimate feedback loop. Differentiating "input" and "output" functions is especially important to the developer, as the effective design of software for these media depends heavily on understanding the unique characteristics of these two interacting processes.

In this regard, Aaron Marcus, a leading graphic artist and designer of visual information systems, has developed a model of "the three faces of information" (Marcus, 1984).

We have found this model especially helpful in designing and evaluating interactive educational technology systems, and we have elaborated Marcus' model here from our perspective (with our own re-interpretations):

1) **Interface**: Technology, both hardware and software, and overall related design considerations, for any system designed to respond to commands and information from the user (learner). Good human interface design should optimize "Input" (Picodyne, 1986). Examples of input technologies include: the mouse, windows, pull-down menus; touch screens and panels; graphics tablets, special keyboards (e.g., for young children, the handicapped, etc.); biofeedback; eye tracking (for monitoring focus of attention, levels of awareness, and subtle control signals); joysticks and track balls; light buttons; and speech recognition or voice-activated devices.

Of particular interest just now are devices and environments which extend the power and flexibility of input from hands on a keyboard to the whole body (Kruger, 1983). For example, with "gesture gloves" and "body suits," students can wear input devices which allow them to interact with complete environments by pointing, gesturing, and moving in three-dimensional space (Foley, 1987). "Programmable" children's dolls and toys are now available in which the programming is done by voice commands, movement, and touch (Worlds of Wonder, 1987). Also, the use of video cameras as input devices can provide feedback about facial expressions or body postures, a true mirror reflecting more than just the consicous responses (Wolman, 1987; Tannenbaum, 1981).

The Interface is the pipeline from the person to the machine. When coupled to carefully designed "outerfaces" (see below), powerful teaching and learning systems may be created. Developers and designers should consider all of the many ways that a person has of expressing himself as possibilities for input to the machine.

2) **Innerface:** The form or structure in which algorithms or programs are written. Visual programming languages, for example, offer a new dimension in the design and testing of educational material. Other forms of representation include scripts, story boards, flow charts, decision tree diagrams, and associational webs and "hypertext" (Nelson, 1981, 1974; Conklin, 1987). Artificial intelligence, such as natural language comprehension and expert systems, is both a part of the interface and the innerface. Developers should consider the recent contributions from cognitive science in designing systems and languages which are to be used by a diverse community of authors, teachers, and artists.

3) **Outerface**: The way in which content is communicated to the learner. For example, communicating visual information may include: text (in many different type fonts or emphases), numbers, graphs, color, icons, diagrams, animations, "menus," maps, or video sequences. Sound also has a crucial, if often subliminal, role in this process (witness the importance of soundtracks of great movies). This is the expression of "Output," the pipeline from the machine to the person (Picodyne, Ibid.). The organization of the display of this information is also especially important, whether it be for a book, computer, or television.

Each output transmitted from the machine to a learner's senses, by way of the interface, is a bridge to the next feedback cycle. Designers should consider all of the many ways that a person picks up cues and patterns when sensing the outside world of stimuli. There are many neurophysiological and psychological parameters that can be profitably brought into play. In fact, the neurosciences are contributing more and more to cognitive science in the understanding of perception and memory (Gardner, 1985).

In addition, we have added a fourth dimension to this model :

4) **The Human-Face**: The psychological models and internal knowledge representations of both the learner and teacher (Collins and Stevens, 1983), including personal experiences, associations, motivations, attitudes, and expectations. Intrinsic motivation (Lepper and Greene, 1975, 1979; Malone, 1980), the affective domain (Brown, et al., 1969; Covington and Beery, 1976), and other social and cultural factors are especially important here -- those of the author and the teacher, as well as those of the student and his/her friends. It is here that cognitive science research meets educational realities.

The educational technologist, working with these four dimensions, molds hardware, software, teaching algorithms, and content to an intimate conformation with the individual student, the teacher, and the community.

Three Areas of Focus

We have taken three areas of educational technology research and development that are closely tied to the above model as foci for our own study of innovation in this field. Each area really combines elements of all "four faces," especially by empahsizing the human teaching-learning dimension. Therefore, in order to provide background for the historical and trend analyses given below, each of these focus areas is elaborated here in some detail:

1. Human-Machine Interface Research

This area, summarized in Marcus' model above, is elaborated both in the "Historical Retrospective" and "Megatrends" sections which follow.

2. Authoring: Tools and Algorithms

"Authoring" is a term used for the specification, design, and preparation of content for interactive media. While an author and illustrator mold words and images into a structured printed form, as in magazine articles, short stories, or books, an author of interactive material must go even farther, as his/her material is presented in a *dynamic* medium, constantly changing depending upon the response of the user (Kay and Goldberg, 1977).

In the earliest days of interactive computer education, most authors were programmers. However, teachers and other content specialists now commonly interact with programmers and graphic artists to form authoring or design "teams." Consequently, over the past three decades, tools have emerged to make this process more accessible to those with little (if any) background or experience in computer programming.

Thus, the central purpose of any authoring tool is to eliminate one of the usually assumed prerequisites for the creation of instructional software: the knowledge of a computer programming language (e.g., BASIC, "C," Pascal, or Assembly Language). Instead, the traditional authoring tool provides the educator with simple, English-like commands and constructs for building instructional programs. Ideally, by freeing the educator from the bonds of computer programming languages, the authoring tool simplifies the process of developing instructional software and incorporating that software into the curriculum. As Bork (1984) notes,

> [A] major responsiblity of a design system is to make certain that the system will attract the best possible teachers in the world, teachers who have insight in how students will behave. At a time when no adequate overall theories of learning exist it is the knowledge of these excellent teachers that gives us the best possible opportunity to produce highly effective learning material.

Yet, even with this description, the notion of an authoring tool is still somewhat vague. What is an authoring tool? What isn't an authoring tool? Why isn't a programming language an authoring tool? To clear up some of the confusion, authoring tools are usually divided into two categories: authoring *systems* and authoring *languages* .

It is often difficult to distinguish authoring systems and languages from traditional programming languages, since an authoring system or language, like any programming language, is used to communicate an unambiguous set of instructions to the computer. In a sense, though, an authoring system is "a level above" traditional programming languages: it provides higher-level constructs for the development of instructional software.

Authoring languages provide simple commands for creating instructional programs, and hence are simple, special-purpose programming languages designed solely for facilitating the creation of instructional programs. Authoring systems, while still providing many or all of these low-level commands, provide additional functionality as well: actual lesson frameworks with explicit pedagogical strategies, for instance. To complicate matters, an authoring system may *contain* an authoring language, so that the user can author programs that are beyond the scope of the authoring system's standard functions.

Authoring tools have been used with varying degrees of success in the past several years. For example, at one point in the United Kingdom's Program in Computer-Assisted Learning, 40% of the programs created for higher education were created via authoring systems (Peterson, 1978). Also, the PLATO project at the University of Illinois has made heavy use of the Tutor authoring language in creating instructional software for their highly successful system (PLATO IV, 1974). On the other hand, many traditional authoring tools (a) restrict the author to a limited set of pedagogical strategies (Pollock, 1985), (b) require too much of the author's time and effort (Gillingham, 1986), (c) are not very well-rounded (Hillelsohn, 1984), and (d) lack important facilities (e.g., graphics, animation, videodisc control).

In any event, the purpose of authoring tools is to focus the talents of the author on pedagogy and design and to bring these talents in direct contact with the power of programmable interactive media in the most effective ways possible.

As important as authoring tools are, they are only part of the development story. There are many effective methods of teaching, some based on traditions thousands of years old (e.g., the Socratic method, the "teaching story," dialog and oral analysis of traditional texts, discovery and "hands-on" experiences, games, simulations, Montessori, Dewey, etc.) Any educational experience embodies one or more of these methods.Thus, a vital part of the authoring process is to choose the most appropriate teaching methods and strategies in conjunction with the appropriate metaphors and combinations of media. Only when these methods can be identified, described, and analyzed can they be effectively used as "algorithms" for interactive learning (Collins & Stevens, 1983). An example of one such "meta-algorithm" is included on the next page (Picodyne, 1986).

3. Models of Exemplary Educational Software: Evolving Standards & Design Criteria

During the past several years, an enormous emphasis has been placed on acquiring microcomputers for the classroom, on becoming "computer literate" (Harper, 1986), and on the computer as "object-to-think-with" (Papert, 1980). And yet, even with all the attention paid to educational technology,

> "[G]enerally, teachers have found very little in the way of programmed instruction that integrates with existing curriculum and their own experienced teaching methods. Should they, therefore, retool to fit the demands of the machine? Would that be 'cost effective'? Even if they are willing to do so, which software are they to choose? There is strong consensus among educators that most of what the market has to offer is poor, usually no better than crudely adapted video games with some immediate visual appeal but little intellectual substance." (Roszak, 1986).

There is considerable evidence to support Roszak's "strong consensus among educators" (Blease, 1986; Solomon, 1986; Ploch, 1986; Chandler, 1984). Roszak

A Meta-Algorithm for Interactive Learning and Teaching

Stage 0: PROVOKE ATTENTION

An external stimulus attracts and captures the student's attention for just a moment -- it cannot be forced.

Stage 1: LOOK AT THE STIMULUS

The student chooses to engage the stimulus.

The attention vector is outer-directed.

Stage 2: PLAY WITH THE STIMULUS

The student visualizes different possiblities, moulds the situation with the imagination, hears it, chews it, perceives it tentatively in different ways.

Stage 3: RE-COGNIZE A FIRM PATTERN

The *gestalt* of the situation helps in the crystallization (proximity, part-whole relationships, etc.). A subconscious decision is made as to how this impulse is going to be interpreted.

Stage 4: COMPARE WITH EARLIER STIMULI

Seek matches with previously-stored patterns in memory, or with stimuli presented earlier in the current sequence. Look for similarities.

Stage 5: DISTINGUISH / DISCRIMINATE DIFFERENCES

Find out what the pattern is NOT -- not this . . . not that . . . How is it different?

Stage 6: IDENTIFY / SYMBOLIZE / NAME

Unify. Integrate the experience. Classify by label. "I'm going to call this X."

Stage 7: REST

Digest. Internalize. Incarnate the experience. Allow the incubation to permeate the synapses. Move away from the stimulus for awhile. Sleep on it.

ITERATE. REPEAT THE CYCLE, STARTING WITH STAGE 0.

Interweave this cycle with practice and experience. Apply it in different contexts to cultivate transfer, both horizontal and vertical comprehension and mastery.

himself cites the surprising and disturbing results of a 1984 study by the well-respected Minnesota Educational Computing Consortium (MECC): Of 10,000 educational computer programs studied, only *200* were deemed "of any value".

Although the notion of "exemplary educational software" is not universal, often-cited deficiencies in educational software include:

- Poor design. Many educational programs make poor use of graphics, do not arouse children's interest, or respond poorly to students' confusion and mistakes.

- Narrow pedagogical foundation. The dominant forms of computer- assisted learning in classrooms are "drill-and-practice" and "tutorial" programs, otherwise known as "computer-assisted instruction" (CAI) (Becker, 1985), (Solomon, 1986), (Blease, 1986). Although CAI programs have their place, they often encourage passive, rote learning through text-intensive, multiple-choice exercises, and persistent, uninformative identification of incorrect answers.

- Lack of direct relevance to the curriculum. The computer is meant to be an addition to the classroom, not a replacement for the teacher, and must therefore mesh well with the teacher's objectives. Many educational computer programs, including some which are otherwise exemplary, simply do not match up well with curriculum goals (Walker, 1986).

- Developers' lack of well-rounded expertise. The design and development of an exemplary educational computer program requires expertise in both education and computing. To create an effective, enjoyable program, it is necessary to understand effective teaching and learning strategies, along with effective software design practices. Both programmers and educators are usually lacking in one of these areas, thus, to deal with this problem, it is necessary to form *teams of experts.* Without such expertise, the design and development process suffers.

Fortunately for our children, there continues to be an evolution and growth of quality in educational software over the years. Many outstanding educational programs have been produced in past years, and such programs continue to be designed and developed today. Developers, educators, and parents must ask an important question: What makes these programs exemplary?

In the following section, we chronicle the history of the development of interactive educational software. We then summarize trends for future development, including criteria for the design of exemplary educational software, as well as some examples of such software available in today's market as models for both the developer and consumer to study.

Historical Retrospective of Educational Technology R & D

> "Those who can truly appreciate the lessons of history will feel privileged to re-live them."
>
> -- Paraphrase of G. Santayana

When we consider the applications of computers for teaching that occurred in the fifties and sixties, it seems a miracle that so much pioneering work was done with such unwieldy and expensive equipment. Yet many of the ideas of those times are still fresh and valid, and can be found embedded in systems today. Furthermore, and perhaps most important, the taproots of some of the most innovative educational technology products now in full bloom will historically not be found in education R&D *per se*, but rather, in seemingly unrelated efforts in aerospace, defense, corporate & private "think tank" research, medicine, and efforts even totally outside the sphere of "technology."

In this section, we summarize both very early pioneering developments and a three-decade retrospective of educational technology R&D from 1957-1987. Our focus is primarily on computers and related technology. However, these historical summaries must be taken in the context of the general changes that were occurring in education and society, both on a national and international scale. (For more extensive historical background, especially in the area of computers and information technology, the reader is referred to Rheingold's Tools for Thought (1984); for a history of the changes in psychology which gave rise to modern cognitive science during this period, see Gardner's The Mind's New Science (1985)).

1940-1956: Pioneering Years

Even in the forties, during the Second World War, the earliest modern computers (although analog machines) were applied to education -- as trainers for pilots and navy gunners. The development of air flight simulators was the direct ancestor of the field of human factors research, the psychology of complex skill acquisition, and human interface design. It was also one of the conceptual bases for the later use of computer simulation as a major tool for research and education.

One of the greatest visionaries of this period was Vannevar Bush (1945), President Roosevelt's Director of the Office of Research. As a result of his experiences in directing over 600 of the nation's brightest researchers, many of those in the Manhattan Project, Bush predicted radical changes taking place in all aspects of academic, scientific and industrial work due to the coming "information explosion."

Bush envisioned the need for a personal information-manipulation device, which he called a "memex," based on individual associative thinking and browsing techniques as early as 1945. His ideas influenced a few, selected researchers during the following two decades, as outlined below; however, it was to be nearly three decades later until widespread references to his ideas came into the mainstream of computers and education (Apple Computer, 1987; Lambert & Ropiequet, 1986; Weyer & Borning, 1985; Rheingold, Ibid.).

The late 1940's and 1950's were years of significant theoretical research in the areas of cybernetics, neuroscience, and information theory. It was also the time during which the term "artificial intelligence" (AI) was born (1956). And it was during these years that IBM began to market commercial electronic digital computers.

1957-1966: Man-Computer Symbiosis, The Augmentation of Intellect, and Interactive Teaching (Mainframe Computers)

The origins of the ideas for using computers for teaching and learning occurred in a number of different settings, each representing quite different philosophies.

Focus: Human-Machine Interface Research

Douglas Englebart (1963) and his group at Stanford Resarch Institute (SRI), working directly from the ideas of Vannevar Bush, developed the mouse, the chord keyset, windows, and light buttons (now referred to as "menus"), all as parts of a major project to investigate ways to use computer technology to augment human performance. These pioneering efforts, as well as those of J.C.R. Licklider at MIT in envisioning "man-computer symbiosis" (1960) were based heavily on a metaphor using computers as an extension of the human nervous system. This work was originally funded by the U.S. Air Force, and subsequently, by a new department of the Department of Defense, called ARPA (Advanced Research Projects Agency).

ARPA became the greatest single funding source of basic and applied research in computer science during this important period. In addition to funding human-computer interface research at SRI, under the guidance of Licklider and Robert Taylor, ARPA was also behind the founding of the AI Laboratories at SRI and MIT, the building of the first time-sharing computer systems (in which many users could all share the common resources of one mainframe computer), and perhaps its greatest contribution, the development of the first national, multi-site, computer-based research telecommunications network, the "ARPAnet" (Rheingold, Ibid., p. 205-231).

ARPA principals were also directly behind the development of "SKETCHPAD" (Sutherland, 1963), a pioneering interactive computer graphics system, complete with a human-computer interface well ahead of its time (light pen, icons, menus, etc.). Sutherland's work had a direct long-term influence on the entire field of computer graphics and image displays. Indeed, many of his later students and colleagues at the University of Utah in the late 1960's were destined to become the leaders in using computer graphics and animation in the film industry almost two decades later (Lucasfilm, Disney, etc.). The influence of this one program and its descendants (e.g., Shoup, 1979) may still be seen in almost all interactive graphics and painting programs in use on microcomputers today.

It is important to note that very little, if any, of the early ARPA research was focused specifically on educational applications. However, educators who were involved peripherally in these projects or familiarized themselves with this work became major contributors to computer education during the following decades.

Many educational computing projects and metaphors began to take form during these early years. George Heller at IBM/FSD had public school classrooms outfitted with IBM 1620's in Rockville, MD, by 1960. At George Washington High School in Denver, Colorado, students began taking classes in computer programming using Control Data mainframe computers as early as 1961.

Research projects in using computers to assist in the teaching of medicine were among some of the earliest educational applications of computers in higher education. Wallace Feurzeig and his colleagues at Bolt Beranek & Newman (BBN) developed a "Socratic system" which used the inquiry and case study approach to help teach medical diagnosis skills (Feurzeig, 1963). The PLATO project, using a Control Data Corporation 6400 mainframe computer at the University of Illinois, developed considerable material in teaching nursing and medicine (Bitzer, 1966). Similarly, some of the earliest development of specialized "authoring languages" to enable non-computer professionals to develop interactive computer-based lessons were developed by John Starkweather, working at the University of California Medical Center in San Francisco (Starkweather, 1969). This work was partially funded by the National Library of Medicine and the National Institutes of Health.

Other early major Computer Assisted Instruction (CAI) projects grew up in major urban school systems, usually in collaboration with universities or large corporations. These included the work of Suppes and his colleagues at Stanford (Suppes, 1966), Duncan Hansen at Florida State University, and early development efforts by RCA, General Electric, and IBM. However, a major critique of CAI during this period was that too much emphasis was placed on the "potential" cost-effectiveness and too little emphasis was given to understanding the much broader context of educational and pedagogical issues (Oettinger & Marks, 1969).

Focus: Authoring

It became clear to many early researchers in computer-based education that there was a great need to provide tools for educators and curriculum specialists to help them develop CAI courses and related interactive lessons, tools which would not require these authors to be expert programmers. Among the many early approaches, two are noted here because of both their longevity and the spinoffs resulting from them:

- The Socratic System (Feurzeig, 1964). Forerunner of today's intelligent CAI (ICAI), the Socratic System developed at Bolt Beranek & Newman was "...a teaching system which made possible a student-computer dialog, [with] the conversation guided by the computer." The system had no intrinsic teaching paradigms; rather, teaching strategies were "a part of the data provided by the teacher designing the problem." Earliest use of this system included applications in teaching medical diagnosis, including a keyword-driven dictionary of acceptable terms and phrases for the student to use in soliciting information from the data base.

While not an authoring system *per se*, this approach led to later models of mixed-initiative CAI (Brown, et al., 1975), in which the student could query the system, as well as the computer posing structured questions to be answered. This approach is now quite common in "expert systems," computer programs which embed subject knowledge and expertise for making expert judgements and decisions within a given domain. Not surprisingly, medical training continues to be one of the more successful areas of this type of research today in systems like MYCIN (Shortliffe, 1973).

- PILOT (Starkweather, 1965, 1969). Standing for Programmed Inquiry, Learning or Teaching, PILOT was one of the earliest authoring languages designed for non-programmers. Starkweather had not only teachers in mind as authors, but schoolchildren as well. Thus, its simple mnemonic, one-character commands made it easy for a wide variety of authors, many as young as seven or eight years old, to write interactive computer dialogs (Brown, et al., 1969).

A number of expansions and variations of the original PILOT language continue to be used on today's interactive systems, and many of these versions now include extensive access to high quality graphics, animation, and videodisks. Because of the simplicity of its approach, PILOT is still often the first authoring language learned by those wishing to explore developing interactive computer dialogs.

Focus: Models & Design Criteria for Exemplary Software

Education during this era was undergoing a radical transformation, especially in science and mathematics. One one hand, a national priority of improving science education evolved as a result of Sputnik and a push for parity with Soviet space exploration. This work was to lead to several major federally funded curriculum development projects to improve student's understanding of the process of scientific inquiry and thinking (e.g., Science Curriculum Improvement Study (SCIS), Science -- A Process Approach (SAPA), Elementary Science Study (ESS), The Madison Math Project, etc.).

On the other hand, the dominant psychological and pedagogical frameworks in early computer education during this period were based on "operant conditioning" models of behavior (Skinner, 1938), coupled with applied mathematical models of learning (Suppes, 1966) The field of "programmed learning" (Skinner, 1968), originally unrelated to computer applications, became an easily absorbed metaphor and conceptual framework for the development of computer-based learning; the computer could provide complex branching structures which were difficult, if not impossible, in printed programmed instruction (Coulson, 1962). Because so many of the computer education programs developed during this period were based on the programmed instruction model, virtually all "computer assisted instruction" (CAI) came to be identified (inaccurately) with the predominant "drill and practice" model.

While many educators today feel that this format does not take full advantage of the computer's instructional potential, it is interesting to note that the tutorial and drill-and-practice formats developed during this period continue to be quite dominant in many schools today: Computer-based math drills comprise nearly 75% of mathematics computer activity in the elementary grades and 67% of remedial and general math use in high schools (Becker, 1986). This data comes at a time where the number of different available choices for means of using computers in instruction has never been higher.

Summary

In summary, virtually all of these early innovations in computer-based educational technology were funded by the federal government: principally ARPA (Department of Defense), the National Science Foundation, National Institues of Health, and the Office of Education.

1967-1976: Transfer to the Schools and to the Military (Minicomputers, Timesharing Systems, & the Birth of Microcomputers)

By the early 1970's, many school districts around the country already had active computer-based education programs. For example, the Palo Alto Unified School District had a substantial computer program for the deaf and hard of hearing, funded by the California State Department of Education, as well as extensive use of Suppes and Atkinson's CAI programs in mathematics and reading. UNESCO, funded by the World Bank, had a prototype teaching network for the elementary schools in Spain, with modules using both very early microcomputers (Datapoints) and interactive graphics (Imlacs). This program was at the heart of a major educational reform effort, focused on revitalizing teacher education (Spain, Ministry of Science & Education, 1971).

By far the largest and most diverse investment in the early years was in military education and training. A major educational technology survey report commissioned by DARPA (formerly ARPA) in 1973 showed that some form or another of educational technology could be profitably applied to most of its 4,000 courses. The subjects ranged from language teaching, flight simulation, electronics repair, use of complex weapons and equipment, to curricula for children and dependents of servicemen overseas (Brown, et al., 1973)

This decade saw a major diversification of the use of computers in public and private schools. During this period, two major R&D projects received over $10 million of support from the National Science Foundation support in the area of computer-based learning (O'Shea & Self, 1983). These two projects, the large PLATO timesharing network at the University of Illinois (Bitzer, 1965) and TICCIT (Timeshared, Interactive Computer-Controlled Instructional Television) -- interactive two-way cable television (Bunderson, 1974) -- were designed to serve as models for future wide-scale development in computer-based learning. It was hoped that these models would demonstrate the cost-effectiveness of CAI and result in their widespread adoption around the country.

The PLATO and TICCIT projects, while not adopted in nearly the widespread ways anticipated by both funding agencies and developers, did provide excellent models of exemplary software which are now easily accessible on today's microcomputers. Similarly, the results of other NSF-funded projects, such as the Huntington II Computer-Based Simulations Project at the State University of New York at Stony Brook (Braun, 1968-70) and Project SOLO at the University of Pittsburgh (Dwyer, 1974), could be disseminated to a much wider audience thanks to two intersecting technologies: (1) lower-cost commercial time-sharing minicomputer systems from Hewlett Packard (HP), Digital Equipment Corporation (DEC), and Data General Corporation; and (2) the BASIC programming language, developed by Kemeny & Kurtz at Dartmouth College in the mid-late 60's. This programming language was both easy for students to learn and easy to use on a very wide variety of computers. Thus, the Huntington simulation programs could be used with little or no modification on just about any major minicomputer (and later, microcomputer), and Dwyer's approach of teaching students to develop their own programs and instructional modules in BASIC was similarly widely disseminated.

With the development of these programs and associated curricula, there also came the need to collect and refine libraries of different programs so that new teachers and students could see just what was available. Some of this task was carried out by the computer companies themselves; some was organized by local and state educational computer networks. Early examples were TIES and Minnesota Educational Computing Consortium (MECC), as well as the Lawrence Hall of Science in Berkeley (Kahn, 1977).

Focus: Human Interface Research

PLATO (1960's-1970's). The PLATO educational computing system, developed at the University of Illinois in association with Control Data Corporation, contained computer terminals with touch-sensitive, plasma-panel screens. Experiments were also conducted on methods of rear projection of randomly-accessed 35mm slide images (now done through interactive videodisc). These interface technologies are now common in interactive videodisk systems in commerce and industrial training, as well as in new portable computer hardware, such as the GridCase computer (plasma display).

SRI (Stanford Research Institute): The "mouse" pointing device, the chorded keyset, and on-screen "windows" were innovations which arose from the ARPA-funded Augmentation of Intellect project (Engelbart & English, 1968), later to be extended into daily workstation environments at the Xerox Palo Alto Research Center. These environments were already in experimental use with schoolchildren as early as 1968 (Brown, et al., 1969; Stanford Research Institute, 1968).

Eye tracking: In this work, pioneered at SRI in the 1960's and at MIT's Architecture Machine Group in the 1970's, light is bouced off the cornea, and the reflection of this light is "tracked". This reflection information is then transmitted to the computer, and as such, the human eye functions as a "pointer" to a location on the computer's display screen. Because the eye's movements are known to be a direct indicator of one's focus of attention, computer-monitored eye-tracking has been a major tool in the study of visual cognition and perception since this time (Bolt, 1984).

Biofeedback: Similar to eye-tracking, biofeedback provides direct physiological correlates to mental activity. Commonly used now in stress reduction and pain relief, computer-monitored biofeedback is an area with great potential for neuropsychological research into understanding optimal mental activity and performance. Early work in this area was also carried out at SRI (Kantor & Brown, 1970).

Focus: Authoring

Research into the development of new authoring tools, languages, and systems expanded considerably during this period. Some examples of new approaches developed include:

Frame-Based Tools. Tools in this category allowed authors to create programs based on "frames", simple building blocks of instructional programs. Frames contained simple commands for placing lines of text, accepting and judging responses, and drawing graphics. Notable frame-based tools included:

- The authoring tool used in TICCIT;

- TUTOR, the authoring tool for the University of Illinois' PLATO system (PLATO IV, 1974); and TUTOR's later PC-based descendant, TenCORE (Klass, 1984).

Form-Based Tools. Authoring became easier with the advent of these tools, which allowed the author to design instruction by filling in templates, selecting items from "menus", and/or answering multiple-choice questions. These "lesson-generating" programs included such projects as:

- DITRAN, a template-based authoring system developed by Noah Sherman and his colleagues at the University of Michigan and used to produce CAI programs for high school physics teachers in NSF-funded Project COMBASI (Miller, 1972);

- The BLOCKS system, co-developed by the California School for the Deaf and the Lawrence Hall of Science, was one of the first authoring systems for the Apple II which included a library of different text fonts, pre-defined graphics images, mutiple pedagogical presentation styles.

Focus: Models and Design Criteria for Exemplary Software

The growth of time-sharing and more cost-effective minicomputer hardware, coupled with widespread availability of the BASIC programming language, resulted in a rapid spread of educational computing projects around the country. A dialectic tension also began to develop between those who wished to couple more advanced CAI with techniques of artificial intelligence (Brown, et al. 1975) versus those who felt the computer's optimal use was in teaching students how to write computer programs to solve problems in BASIC (Dwyer, 1974) or Logo (Papert, 1980).

Educational technology R&D efforts were supported both by federal and corporate funding at a wide variety of universities, research centers, and museums around the country. Some of the most influential ones during this period included:

- MIT & Bolt Beranek and Newman (BBN): Under the influence of Seymour Papert and Wallace Feurzeig and funded by NSF, the Logo computer language and a computer- programmable robot turtle were developed as part of a discovery-oriented methodology for teaching mathematics (Feurzeig, et al., 1969; Papert, 1980). This project was one of the first widespread attempts to teach young children mathematics by having them using computers to develop their own algorithms and programs, rather than by using CAI-based lessons;

- Stanford Research Institute (SRI): The Education Laboratory, using technology funded by ARPA, was primarily an internally-funded center with emphasis on integrating advanced hardware and interface devices (graphics display terminals, the mouse, biofeedback, eye-tracker feedback, etc.) with programs centering on the affective domain of education (Brown, et al., 1969; Brown & Lewis, 1968). Educational programs were created both by teachers and students using the PILOT authoring language (Starkweather,1966), BASIC, and EUCLID, a graphics-oriented programming language. By being centered between Engelbart's Human Augmentation Laboratory and Charles Rosen's AI/Robotics Laboratory (funded by both ARPA and later, labor unions in Detroit), the Education Laboratory at SRI was thus in touch with the most advanced technology of its day. Thousands of people, from local school children and teachers to international dignitaries and education officials, visited this lab between 1967-1974.

- Xerox Palo Alto Research Center (PARC): The development of PARC was a result of cross-fertilization from ARPA, MIT, BBN, SRI, Stanford, the University of California at Berkeley, and the University of Utah. Advanced mini-microcomputer systems with high-quality graphics displays, mice, and menu-controlled software were developed. Furthermore, the entire research lab was electronically linked, both internally and externally (via the ARPAnet). Similarly, the Smalltalk programming language, a system which was oriented toward manipulating both graphics and text on a very high density "bitmapped" display, became a link between the educational applications of the past decades and hardware-software systems which are common today (Kay & Goldberg, 1977; Goldberg, 1979).

- BBN: Early work in both developing the Socratic system and the Logo programming language evolved in a new direction, incorporating what would later be known as "cognitive science" into CAI. Led by efforts of Jaime Carbonnell (1970), the first "intelligent" CAI system (SCHOLAR) was produced. In this work, knowledge about a subject was integrated in ways such that the computer could be programmed to begin to "understand" the subjects it was helping students learn. John Seely Brown, Richard Burton, and others (1975) began to formulate major conceptual frameworks for expanding CAI in ways that incorporated advances from both AI research and new approaches to knowledge representation from cognitive psychology.

- Education Technology Center, University of California at Irvine: There was considerable activity in improving the teaching of both high school and undergraduate physics during the 1960's and 1970's. Much of this interest was a spinoff from federally-funded curriculum development efforts in this area (e.g., Zacharias' Physical Sciences Study Committee (PSSC), Harvard Project Physics (HPP), the Berkeley Physics Course, etc.) Alfred Bork was one of a small number of physics teachers at this time who saw the great potential for using computer technology in this area, and he developed a center at the University of California at Irvine which is still one of the most active in the country in using interactive technology for teaching science (Bork, 1984).

The Birth of the Microcomputer

Last, but certainly not least, the most important technological breakthrough in hardware came about during this decade. The invention and development of the microprocessor and microcomputer -- a full computer on a chip -- led to the development of an entire industry which is now at the heart of educational technology. Following hand-held, programmable calculators from Hewlett Packard in 1972 (approximately $400 retail), the first programmable microcomputers emerged, including the Altair, IMSAI, SOL, and other computer kits (1974-1976). By 1977, two microcomputer chips were in large scale production, the 6502 and the Z-80. These two chips became the cornerstone for 8-bit educational computing for the next five years (Apple, Commodore, Tandy, and Atari). It also became clear that a stable economic prediction for computer power and price was emerging: Every ten years, computer power increased by a factor of 1000, memory increased by a factor of 10, and price decreased by a factor of ten.

Advances in educational television paralleled the development of computer technology during this decade. While hopes for educational television in the classroom have still not yet materialized, the Children's Television Workshop had an even far greater impact on early childhood education in the home with the development of Sesame Street, The Electric Co., and similar shows. In addition, the quality of programming for older students and adults, including both imports from the BBC in the U.K. and programs on science, nature, geography, and the arts produced in this country, paved the way for future use of video as a major instructional media in both the classroom and the home.

1976-1987: Educational Technology Becomes an Industry (Microcomputers, Videodiscs & Optical Storage Devices)

The first microcomputers in schools included Imlacs, IMSAIs, Sols, and Northstars. Then, in 1977-78 came the Commodore PET, Tandy TRS-80, Apple II, and Atari 800, with each of these companies emphasizing sales and support to the schools. It was during this time that corporate non-profit foundations and institutes were set up by Apple and Atari to promote innovative use of computers in education, as well as legislation designed to increase corporate tax benefits for donating technology to schools. The number of school districts having microcomputers has increased from 38% in 1981-82 to 91% in 1986-87, with density declining from one computer for every 125 students (1981-82) to one microcomputer for every 37 students (1986-87) (QED, 1987). Experiments such as Apple's "Classroom of Tomorrow," in which each child has one computer at school and one at home, will gradually evolve into situations where students no longer are aware that they are using computers *per se*; rather, their materials will embed microcomputers in appropriate ways into the many learning experiences which they encounter (e.g., Kruger, 1982; Tannenbaum, 1981).

The 1980's have followed a similar pattern, accelerating because price performance continues to improve at a geometric rate, the software offerings accumulate, and the public becomes more at ease with the medium. The entrance of the IBM Personal Computer (and similar, compatible computers) into the market in 1981 lent a solid air of long-term legitimacy to the entire personal computer industry. The present epoch is characterized by excellent interactive color graphics, more use of the mouse, and more efficient authoring processes. Some of the best technology today, and an indication for the future, may be found in the 16-32 bit microcomputers such as the Atari 1040ST, the Commodore Amiga, and the newest Apple Macintoshes. In addition to providing excellent graphics, sound, and user interfaces, the high-speed microprocessor in all these systems allows them to run software from other computers (e.g., IBM PCs) by "emulating" the operating characteristics in either hardware or software.

Especially in commercial, industrial, and military training, and in higher education, the use of authoring and prototype multimedia production systems (e.g., the CEIT "Authology" environment), are coming into more and more widespread use. Similarly, advanced software technology using both expert systems and associative memory models is now commonly available for users of many mircocomputer systems.

Both the U.S. government and other nations support education technology development efforts for their own purposes (military, commercial, and civilian), and their direct and indirect support of research and applications contributes to the private sector in virtually every innovation. The most recent examples of this are in the development of interactive videodisk, now commonplace in military and industrial institutions (over 7,000 units in the military alone in July, 1987, according to The Videodisk Monitor). More recently, Japanese and Dutch development of the audio Compact Disk and CD-ROM storage technologies has spurred considerable activity in access to mass information and the need for new software technologies to allow learners to browse effectively for information (Lambert & Ropiequet, 1986).

Paralleling the instructional use of computers, and more recently, interactive videodisks, in schools, military, and corporate settings, has been an increasing growth of microprocessor-based consumer electronics. Hand-held calculators are now commonly available for under $10, with hand-held dedicated "picocomputers" (including small alphanumeric and liquid crystal graphics displays) now available for under $50. Toys and games make common use of advanced speech synthesis (e.g., Texas Instrument's "Speak and Spell"), voice activation, and most recently, voice recognition and sensation of movement and light (Worlds of Wonder's new "Julie" doll, complete with an advanced AI chip for "understanding," motion detectors, and light sensors).

Perhaps the most important new consumer electronics advances during this decade have been in the area of video and audio. Videocassette recorders are rapidly replacing traditional 16mm film projectors in schools, as well as penetrating the home market in ever increasing numbers. Compact audio disk players (CD) provide unprecedented noise-free digital sound. They have dropped in price by over a factor of ten in less than four years (from $1200 to $120 since 1984).

Focus: Human-Machine Interface Research

Icons, menus, browsers, overlapping windows, and the bitmapped display. Much of this technology resulted from the Alto project (Thacker et al, 1979), and the Smalltalk (Learning Research Group) project (Byte, 1981) at Xerox' Palo Alto Research Center.

The "Arch Mac" Group. MIT's Architecture Machine Group (Bolt, 1984) developed a number of innovative projects within the context of their "Media Room" project, including (a) the "Movie Map", which facilitated "driving through Aspen" via a videodisk, computer-based road map, and touch-sensitive monitor, (b) "Put-That-There", a speech and gesture experiment, and (c) "Dataland", a system for spatial data management.

Commercial Products. Much of the 1960's and 1970's technology mentioned above has reached the consumer in the 1980's. Xerox' Star system (Smith et al, 1982) contained many of SRI's and Xerox' innovations (e.g., bitmapped display, the mouse, icons, menus, overlapping windows). Apple Computer refined these innovations and made them more affordable in their Lisa and Macintosh systems, and other companies quickly incorporated the innovations into their products (e.g., Microsoft's "Windows" for the IBM-PC, PC, Commodore's "Amiga" computer, and Atari's "ST" line of computers).

In addition, a variety of microcomputer interface devices became available (Buxton, 1986), including the "Muppet Learning Keys" keyboard for children (Koala Technologies, 1985), graphics tablets, joysticks, trackballs, mice, light pens, and speech input/output devices.

Focus: Authoring

With the advent of the consumer videodisc player, authoring tools that facilitate the prototyping and production of multi-media software are becoming more widespread. Such tools include Authology (CEIT Systems, 1986) for IBM PC-compatible systems and Apple's HyperCard for the Macintosh. These tools are now being used extensively in higher education.

The authoring tools developed during the 1960's and 1970's are often used to create what Gagné (1981) calls "traditional programmed instruction of the branching type," i.e., programs which ask a question, judge the response, then branch to another question and repeat. Most of these tools focus on providing facilities for the creation of drill-and-practice and tutorial programs, rather than simulations, microworlds, or learning games. By restricting the author to limited (and often not effective) pedagogical strategies, it becomes easy to create dull, lifeless, ineffective software. As one critic notes, "Easy creation of ineffective software is not progress" (Pollack, 1985).

In the 1980's, new authoring tools have allowed authors to focus more intensely on instructional design, rather than on program design.

Graphical Tools. The availability of low-cost, high-resolution, "bitmapped" displays (Thacker et al, 1979) led to the development of highly graphical authoring tools. These tools allow the author to (a) manipulate stylized graphical objects ("icons"), which represent the building blocks of instructional programs, and (b) draw a program's graphics, via the "mouse" pointing device, directly on the computer's display screen.

- CMU Tutor (Sherwood & Sherwood, 1986), the latest descendent of Control Data Corporation's Tutor authoring language and the University of Illinois' MicroTutor authoring language. CMU Tutor, developed within Carnegie-Mellon University's Center for Design of Educational Computing, features a graphics editor which automatically generates or modifies code in the "C" programming language. In addition, the system runs on a variety of host systems; programs written with CMU Tutor run without modification on any of these systems.

- Course of Action (AuthorWare, 1987), a Macintosh product currently in beta-test, is targeted at K-12 educators and the computer-based training market. In Course of Action, the author uses all of the Macintosh's standard user-interface features (menus, windows, buttons, dialog boxes, and icons) to create iconically-represented lessons.

Spatial Metaphor & Simulation "Kits". Early experimental systems developed by members of the Learning Research Group at Xerox PARC focussed on the metaphor of "construction kits" (Goldberg, 1979). Examples included "ThingLab" (Borning, 1979), a kit allowing specification of a mathematical simulations defined by constraint conditions; "Game-X" (Kahn, 1981), a kit for designing and testing inquiry and discovery learning games for developing strategic thinking; and the graphical "Simulation Kit" (Goldberg, Ibid.). These efforts were followed by a number of projects sharing a similar philosophy, but oriented specifically for teachers as authors of their own computer-based curricula:

- Programming by Rehearsal (Gould and Finzer, 1984), developed at Xerox' Palo Alto Research Center (PARC), provides an environment called the "Rehearsal World" for the creation of educational software. The Rehearsal World provides educators with a uniform metaphor (the theater), and an exploratory environment in which highly interactive, graphical, educational activities may be created by "rehearsing performers" (programming by example and by manipulation of graphical objects).

- The Alternate Reality Kit (Smith, 1986), also developed at Xerox PARC, provides an environment for creating interactive, animated simulations of "toy universes", in which normally inaccessible laws of nature (e.g. gravity) become accessible as on-screen "interactors." The purpose of the ARK is "to help students develop deeper intuitions through seeing the normally abstract and immutable rules of nature as accessible, concrete objects which can be examined and modified. "

- Invent! (Zauderer, 1987), currently under development by the authors, will allow educators to create and customize "directed exploration environments": explorable, highly interactive learning environments for children.

Modern hardware and software has gone through countless generations of usage, interpretation, and revision. Top-down design is only possible after many broad attempts at bottoms-up implementations have been worked out. A process of educational technology "darwinism" ("survival of the educationally fit") is functioning for us, where products and systems are released, exercised in vivo, and the results analyzed thoughtfully, going through many iterations to evolve correctly. There is no other way, no shortcut to quality. This implies that developers should not wait to attain perfection before releasing their products - rather they should build their systems with provisions for an easy succession of revisions.

Focus: Models of Software Development Environments

Educational technology development now takes place in many different environments. In contrast to the 1960's-1970's, when development was primarily done at universities and large research centers, software is now developed by individuals in their homes, school teachers, and in many of America's largest corporations. Three educational development projects are summarized here, each based on a specific prototypical case study. These examples are included to demonstrate a number of factors related to how innovation and diffusion of educational technology development occurs. Thes were also chosen both for their diversity and for the characteristics they share in common.

Public High Schools:
Computer Laboratory, George Washington High School, Denver, CO (Dr. Irwin Hoffman, Director (retired)), 1960-1987.

Classes in programming computers have been a part of this high school since its first years. The George Washington computer program, featured as a one of ten case studies, in conjunction with its inclusion as an exemplary computer education projects in a national HumRRO Study (Hargan & Hunter,1978), was begun by a collaborative effort of a mathematics and tennis teacher (Irwin Hoffman) and a systems analyst for Control Data Corporation (Bob Albrecht) for an advanced mathematics class of sophomores in 1960. Within two years, five of these students were already pursuing individual research projects in applied mathematics, entering their programs on punched paper tape on a small CDC mainframe computer (Albrecht, 1963).

Awards and equipment grants, both federal, local, and private, were made to this program over the years. The Lab now has well over 60 microcomputers, as well as hundreds of different software programs. A special local PBS TV documentary was made on the Computer Lab and its activities, and a special meeting of the Advisory Board of the Atari Institute for Educational Action Research was held there in1983.

Of special interest to this report was a federal Title VII grant to the State of Colorado to this project, via the Denver Public Schools, for project LIRIC, the development of microcomputer-based teaching modules in bi-lingual education (Electronic Learning, 1984). Nineteen high school students, under the guidance of Dr. Hoffman, two additional faculty and staff members, and adult foreign language specialists in Spanish, Vietnamese, Laotian, and Hmong, created 40 lessons in thse four languages between 1979-1982, with a total budget of $250,000. Using early Apple II computers, students created their own foreign language word processor software for each of the four languages; they created their own authoring software (as none was available from Apple at this early date, nor would any have been appropriate for this project); and they designed all the foreign language alphabetic characters, under guidance from the adult consultants.

For this project, some students received Advanced Placement course credit during school hours and were paid after school wages for their additional work. The students who worked on the project used a combination of the Applesoft BASIC and Assembly languages, and their work included development of an entire courseware management and recordkeeping system. This software is now in use in many Colorado schools (free of charge), on loan to the Department of Education in Oklahoma, and has been sold to schools in Utah, California, and several other states. A special fund was established so that a percentage of sales would be used to set up an international electronic telecommunications network for students to communicate with others living in Laos, Cambodia, Vietnam, and several other countries.

This is not the only such student-developed software project that took place at this high school, nor is it unique that a teacher could recognize potential talent in his own students so that they could, in fact, develop courseware and educational materials for other students (e.g., Bearden, 1987). However, the fact that Dr. Hoffman continued to teach in this project for over 27 years and was ultimately awarded the 1983 Presidential Medal for Excellence in Mathematics and Science Teaching is quite a statement of success.

What is unique about this environment is Dr. Hoffman's commitment to a non-traditional way of viewing the roles of teacher and student: Students are seen as creative researchers, capable of directing their own learning, with guidance and facilitation by a master teacher. Collaboration goes on here in concert with normal classroom competition in other courses; students help each other, choose projects that are worthy of their energies and talents, and they are committed to excellence. The staff assists by providing guidance, but Dr. Hoffman (and earlier, Bob Albrecht) would readily admit that his better students can know a great deal more than he does about both mathematics and computers; his job is to function as a mentor, a facilitator, and a role model (Incidentally, many of his former students are now in top jobs with major computer-related companies around the country, as well as being researchers at many universities).

The idea that students can, in fact, be developers of high quality educational software is not a widely accepted concept in education. However, this project proves that it is possible, once a teacher has the courage to view students as being more than capable at such a task (Blair & Lobello, 1984).

Science Museums:

The Lawrence Hall of Science, University of California, Berkeley (1970-1987)

The Lawrence Hall of Science (LHS) has been one of the major centers for innovation in the development of science education and teacher training for almost twenty years. As a part of the Berkeley campus of the University of California, it has thus attracted top faculty and students interested in all aspects of research and development in science curriculum development and training. The vast majority of its R&D money in education has come from the National Science Foundation, as well as from corporations and foundations. In 1978, it had over 200,000 visitors.

The first major computer project funded at LHS was an NSF-funded CAI project in teacher training for new high school physics teachers using the Harvard Project Physics curriculum (Miller, 1972). With the support of the LHS Assistant Director and

Mathematics Specialist, two staff members of this project realized the need for beginning to introduce children to computers. At this time, there were few places in the country (other than a few school districts and research labs) where large numbers of students could have a hands-on experience in using educational software or in programming.

As an offshoot of classes in using small, electronic calculators, public classes in the Computer Education Project at LHS were thus begun by Hesh Wiener, Ray Westergaard, and Ted Kahn, with the support and assistance of LHS Assistant Director Bob Content in early 1971. The original program used two minicomputer systems, a 32-terminal Hewlett Packard system and and a NOVA system from Data General. Much of the system software for this latter system was programmed by two students, one in high school and the other, a graduate student. Student terminals were primarily alphanumeric teletypewriters, which were later complemented by inexpensive robot "turtles," graphics plotters and displays, and ultimately, microcomputers.

The program grew quickly from its three original classes, and it attracted a number of undergraduate and graduate students from the Berkeley campus. The project hired a director, Bob Kahn, who coordinated curriculum and staff development. (Note: Kahn was a former student of Dr. Irwin Hoffman at George Washington High School in Denver). Within two years, there were well over two dozen different classes and special groups, including several groups for local schools. It is also important to note that at this time, there was no other major timesharing computer facility available on the Berkeley campus; thus, this project began to attract the attention of a number of faculty members, as well.

The growth of this project, which was also cited as a HumRRO exemplary case study (Hargan & Hunter, Ibid.), was substantial over the years and became a major model for other science museums and children's museums (Kahn, 1977). By 1978, over 30,000 visitors and students (15% of the total visitorship) came to participate in either computer classes or related experiences. The original BASIC programming curriculum was expanded into teaching the PILOT language to younger kids, problem-solving and productive thinking, as well as later experiments in interdisciplinary curricula development (e.g., biology, astronomy, and computers). Mathematics classes became a major offshoot, resulting in the development and growth of the EQUALS Program, one of the nation's best training and dissemination models for mathematics education for girls, minorities, teachers, and parents. Seminars were developed, in conjunction with other institutions in the San Francisco Bay Area, including SRI, Xerox PARC, Stanford, and teacher training became a major focus in the late 1970s. Furthermore, with the arrival of Dr. Arthur Luehrmann, NSF-funded computer-based exhibits were also initiated, as well as a substantial outreach program using a mobile "computer van" for schools. Perhaps most important, as computer use grew and microcomputers became available, LHS developed one of the largest educational software libraries in the country.

Museums are important environments for educational technology for many reasons. First, such environments are informal learning settings which have different dynamics than the average classroom, and thus, are much more open to early innovative ideas (Rosenfeld, 1982). Second, they are excellent training grounds for future developers. Of the staff of 30 people involved in the LHS computer project in 1978 (including students), 70% are now professionally involved in some way or other in computer-related fields. Ten have continued to have substantial professional involvement in major educational development or marketing companies (CTW Software, Computer Literacy, Hakansson Associates, Apple Computer, Atari, Picodyne, Advanced Ideas, Information Access, etc.).

Finally, access to excellent science education materials and senior staff created an interdisciplinary working environment which, as suggested below, is now strongly needed to advance the state of the art in educational technology. In fact, many science and children's museums now have active computer education projects and interactive computer or videodisk-based exhibits (e.g., the Capital Children's Museum, Boston Museum of Science, the Franklin Institute, Indianapolis Children's Museum, Exploratorium, Children's Discovery Museum of San Jose, etc.). Many of these institutions have developed or collaborated in development of commercial educational software. Thus, such museums could serve as a major part of a national network of educational technology centers.

Corporate Training:

Syntex Laboratories, Palo Alto, California: Training & Education Department
(Computer-based training and interactive videodisk; 1983-1987)

Syntex Labs, a division of Syntex Corporation, is a major pharmaceuticals research, devlopment, and marketing company. Its pioneering products have included the first oral contraceptives and Naprosyn™, a leading non-steriodal anti-inflammatory drug used for treatment of arthritis and pain relief. New products will soon be released for both the gastrointestinal and cardiovascular systems, as well.

Picodyne began helping individual departments at Syntex (e.g., Medical Services in Marketing) to use microcomputers for continuing education of physicians at special medical conferences as early as 1983. An expansion of the programmed instruction, case study format led to timed, interactive games in diagnosis and treatment in 1984, and experiments in using advanced natural language interactions for sales data synthesis were carried out in Fall, 1984.

A major planning study was commissioned by Syntex's Training & Education Dept. in 1984. By 1988, there will be nearly 1,000 product marketing representatives (sales reps) for Syntex Labs. Training these people, whose backgrounds tend to not be in science or medically-based fields, is an extensive task. These trainees must learn pharmacology, anatomy, physiology, product knowledge, and human relations and sales strategies. The 1984 study thus recommended that Syntex institute a major shift to home education and that this be accompanied by extensive computer-based training (CBT). The plan envisioned each new sales rep ultimately having a personal computer in his or her home for initial acquisition and later review of this extensive training material.

Picodyne subsequently won a bid to develop CBT modules for Syntex in 1985. Using an internally developed authoring system, Picodyne hired writers and a contract graphic artist, and has developed 13 separate modules, representing well over 25 hours of training material, nearly 1500 separate graphics images, and thousands of lines of text. These modules include interactive tutorials, with "hypertext" links to technical vocabulary (on-line glossary), diagnostic tests and practice exams, a wide variety of interactive games, and case study simulations for both diagnosis and treatment of disease states and strategic sales simulations.

The total cost of this project has been approximately $400,000 over two years, including both internal Syntex costs and development costs. The process of design and development has integrated a great deal of developer knowledge from work with schools, children, and advanced human-machine interface design, in conjunction with high-level expertise from Syntex staff and consulting physicians. Individual modules have been designed and prototyped by writers (authors) in as little as two-three days, with extensive field testing, revisions, and editing done over much longer periods of time. This is a common aspect of software development: Powerful tools may cut down initial development time by a substantial degree; however, the greatest required time tends to be in continuous refinement and editing.

Furthermore, a side-effect has resulted which will begin to be more and more common in other settings: Standard printed training materials are now being revised to be more and more oriented to the style and design format of the CBT training program. Thus, the introduction of CBT into the training system has now influenced the way other training media are conceived and produced.

Syntex also represents patterns of educational technology innovation in corporations which are both similar and quite different from those found in schools: Corporations understand the need for continued training and development of employees, especially those in sales positions whose performance is at the basis of the comapny's bottom line. Thus, while there may be some initial management resistance to large capital expenditures for "computers," per se, there seems to be little disagreement on the need for effective training courses. Such courses are more and more shifting to the use of CBT and interactive videodisk because of the high costs of individual instructors, the high travel costs and off-job time loss associated with large group seminars, and the desire of employees to do this training at the time of their own convenience. According to industry statistics, it is therefore not surprising that corporate training and marketing uses of extensive CBT/interactive videodisk systems far surpass those of any other market segment except for military training (The Videodisc Monitor, 1987). This is one area where schools, corporations, and the military have a great deal to learn from each other's experiences.

Factors and Trends Influencing Innovation in Educational Technology

Many modern developers of educational technology know very little about the older historical antecedents which have preceded their efforts. This is not surprising, as many have come to this field only during the past decade, during which microcomputers have been almost the sole primary focus of public attention regarding technology in education. However, in order to understand trends and factors contributing to innovation, it is very important to remember that interactive educational technology has a substantial historical basis.

In this section, we will summarize what has been learned from three decades of research and development in educational technology, predict what to expect over the next five years, and generalize by stating a number of "megatrends" which will continue to influence the use of technology in education.

Human-Machine Interface Research

Much of the current work in human-machine interface design can be grouped into the following categories:

- "Direct Manipulation" Interfaces. (Shneiderman, 1984) This approach, pioneered at SRI and Xerox, is embodied today in, for example, the Macintosh computer. It involves direct user contact, via such input devices as the "mouse" (or the "DataGlove"; see below), with on-screen graphical objects. Rather than typing strings of text, the user gives the computer instructions and performs actions directly, by manipulating, managing, and arranging the objects involved.

- Multi-Sensory Experiences. Foley (1987) describes a "virtual environment" developed at NASA's Ames Research Center (Mountain View, CA), in which a head-mounted computer display produces manipulable, three-dimensional scenes and images. The wearer also wears a DataGlove, developed by VPL Research, Inc. (Redwood City, CA) to communicate with the system and manipulate computer-generated objects via hand gestures. The DataGlove is currently a hand-gesture input device, but it will soon become a tactile-feedback output device as well; as the wearer "handles" computer-generated objects, the DataGlove will transmit sensations of weight or texture to the wearer's hand. VPL Research of Redwood City, CA, is currently generalizing the DataGlove's technology in a "DataSuit", an entire suit of clothing that will allow full-body input and output.

- Interface Design as a Discipline. Human-machine interface design is coming into its own as a full-fledged field of research. It has united such areas as "human factors" (Kantowitz, 1983), "ergonomics", the psychology of human-machine interaction (Card, Moran & Newell, 1983), and "software psychology" (Shneiderman, 1986), in the pursuit of highly optimized user interfaces. Textbooks on user-interface design are appearing, (Heines, 1984, Heckel, 1984, Norman, 1987), and universities are beginning to offer classes on the topic (Verplank & Kim, 1986).

- Collaborative Systems. Computer-supported cooperative work is a booming research topic at the moment. The first conference on the topic was held recently, and a number of organizations, including Xerox PARC (Stefik et al, 1987), have significant research efforts underway in the field. As Malone (1985) argues, "it will become increasingly important to extend our concept of *user interfaces* for individual users of computers to include *organizational interfaces* for groups of users."

- Rapid Prototyping. Quick and efficient "mock-up" of user-interfaces is an increasingly important part of computer software design. Software designers understand that the interface is the most important component of a program. As such, designers are interested in a rapid prototype-test- modify cycle for interface design (Henderson, 1986), and have built computer-based tools to support this cycle. These "user-interface management systems" (Myers, 1987) enable the designer to design, implement, test, and modify highly complex interfaces.

- "Intelligent" Interfaces. Each user of a software system has different needs, a different learning style, and a preferred style of interaction with the machine. Ideally, a software system would be "adaptive"; that is, it could "adapt" its interface to each user's needs. Frye and Soloway (1987) note that an educational program's user interface "must be sensitive to the general skill and/or developmental level of the user", and that if an interface cannot span differences in skills or development, then the interface "may be of very limited utility in education." Work on adaptive interfaces will result in highly flexible, highly usable software in years to come.

Authoring: Tools & Algorithms

Authoring is now experiencing rapid growth in use of "associative tools." The idea is to make educational applications match more closely the natural associative processes which we use in thinking, especially because of the availability of multi-media. These tools include "hypertext" systems (Conklin, 1987), which facilitate information management, thinking, and communication in a navigable "information space". The latest commercially-available, microcomputer-based associative tool is Apple Computer's HyperCard (Goodman, 1987), which allows the user to create and link together "cards" of intermixed text, graphics, videodisc images, and sound. HyperCard also includes a powerful, but simple, programming language. In tracing HyperCard's "lineage", a number of systems stand out, including:

- Memex (Bush, 1945). A personal information device which could collect, sort, cross-reference, and keep track of the most important contributions in one's own and related research fields. The forerunner of today's "hypertext", "idea processing", and "outline processing" systems.

- NLS (Engelbart & English, 1968). Engelbart envisioned the "amplification" of the user's intelligence through the use of a multiperson, distributed conferencing and editing system.

- Xanadu (Nelson, 1981). Nelson envisions the system as a means for creating an on-line version of the entire world's literary corpus.

- Augment (Engelbart, 1984). The continuation, at McDonnell-Douglas Corp, of Engelbart's NLS work at SRI. Users use a "mouse" and an optional one-handed "chorded" keyset to facilitate efficient individual and collaborative text processing.

- InterMedia (Garrett, Smith, & Meyrowitz, 1986). Developed at Brown University, InterMedia is "a tool for professors to organize and present their lesson material via computer", and is "an interactive medium for students to study thet materials and add their own annotations and reports" (Conklin, 1987).

- NoteCards (Halasz, Moran, & Trigg, 1987). Developed at Xerox PARC, NoteCards is "an information analyst's support tool" (Conklin, 1987), a tool that helps the user gather information about a topic and produce analytic reports about that topic. Like HyperCard, the system is based on the "card" metaphor.

Models and Criteria for Exemplary Educational Software

Educational software has now been in widespread use for over 20 years. As summarized above, the widespread use of the microcomputer has expanded the number of metaphors, teaching and learning idioms, and interacive play and learning styles in today's products. Simultaneously, there are strong feelings among many edu~~cators that far~~ too many of today's products suffer from poor quality and design, and that developers and publishers of these products must set higher standards for future products if they expect them to be used extensively in the schools.

Guidelines for Educational Software Design

In our view, effective, enjoyable educational software must be based on sound, accepted design principles. However, with some notable exceptions, there has been little discussion of exactly what these principles are. The number of publications on this topic is small, there are very few university-level programs of instruction in Educational Computing, and the amount of communication between developers is limited.

The guidelines that we present here -- that educational software should be *powerful*, *playful*, *esthetic*, and *usable* -- have been synthesized from several sources: Ann Piestrup McCormick's guidelines as developed at The Learning Company (Piestrup 1983, 1984, 1985), the work of Tom Malone (1980), and our own experience (Brown & El-Ghannam, 1973, Zauderer, 1987). Note that this is a list of ideals; it is unlikely that any one piece of software will embody all of the criteria mentioned here.

Major Guideline 1: Good Educational Software Is **Powerful**

Adaptive	Increasing, manageable, and cumulative levels of difficulty; smooth transitions.
Constructive	Parts and tools can be used to build new elements.
Current	Up-to-date content and features.
Customizable	Can be tailored to fit teachers' and students' needs.
Enduring	Children enjoy reusing/replaying it; the presentation and concepts have staying power.
Exploratory	Many approaches and paths. Many options, patterns, and solutions.
Focused	Clear educational objectives; correct scope.
Guided	Clear and useful on-line "help" available. Prompts and clues given when appropriate.
Integrative	Complete and consistent. Integrates with curriculum and other learning experiences.
Structured	Lays and builds upon foundation; relates elements to one another.

Major Guideline 2: Good Educational Software Is **Playful**

Active	Program involves the child in active learning.
Challenging	Maintains child's interest; doesn't slow the child down.
Elegant	Sophisticated; complexity handled simply.
Endearing	Cute characters, scenes, animations, sounds.
Engaging	Captures and holds the student's interest and attention.
Exciting	Fast action; risks; timing; competition.
Humorous	Funny or unexpected events.
Imaginative	Engages fantasy: theme, characters, storylines, whimsy.
Intriguing	Matches children's interests; approachable; immediately engaging; arouses curiosity.

Major Guideline 3: Good Educational Software Is **Esthetic**

Useful Text	Brief, clear, concise; appropriate for child's reading level; carefully formatted; used only when needed.
Delightful Sound	Catchy, melodic, upbeat.
Meaningful Graphics	Convey educational content; sophisticated; appealing; high-quality animation.
Personalized	The child is informed of the consequences of actions; feels a connection with the program.
Positive	Warm; inviting; non-judgmental; fosters a sense of success; encourages self-esteem.
Relevant	Uses a rich variety of children's phrases, idioms, and allusions.
Rewarding	Satisfying; closure and completion.

Major Guideline 4: Good Educational Software Is Usable

Affordable	No esoteric hardware required. Minimal teacher training required.
Appropriate	Easy to integrate into the curriculum. Augments, rather than replaces, existing classroom resources.
Child-Controlled	Child controls exploration and learning.
Cooperative	Encourages joint problem-solving.
Easy to Use	Clear way in and out of the program; straightforward procedures. User interface is intuitive.
Multi-Faceted	Many possible uses in the curriculum.
Non-Violent	No violent elements.
Non-Exclusive	Interests boys and girls; interests children of all socio-economic and ethnic backgrounds.
Responsive	Responds clearly, quickly, and effectively to child's input.
Robust	Bug-free; clean, unconvoluted code. No unnecessary disk-swapping.
Well-Evaluated	Rigorously evaluated according to accepted principles of curriculum evaluation.

Exemplars

Several hundred excellent educational software products have now been produced, and the number may double in the next five years. Such products include not only microcomputer programs for Apples, IBM PCs, Tandys, Ataris, Amigas, and Commodores, but also a growing number of interactive videotapes, laser disks, and multi-media packages.

One sign of the growing maturation of these media is the great diversity of products produced. Below is one classification scheme that demonstrates the wide variety of formats of current commercially-available educational software. Note that these categories are not distinct; much software falls into two or more. Because of the wide range of individual differences in learning & teaching styles, preferred modes of presentation, and student interests, each of these categories has special merit at different times and for different students. (Note: When specific titles and publishers are listed, they are for illustrative purposes only. Examples are not necessarily intended as either an endorsement by the authors nor as being the best available examples of a particular genre of educational software).

Balance Beam. Equations, mathematics, physics, symmetries, economics, social subjects. A metaphor for "find what makes these equal."

* **Black Box.** Guess a secret rule, find hidden patterns, perform experiments on systems to predict or explain puzzling behavior. "Gertrude's Puzzles," (The Learning Company, 1982); "The King's Rule" (Sunburst Software, 1983); "Baffles" (Conduit).

* **Computer-Controlled Monitoring.** "Microcomputer-Based Labs" (TERC, Atari, Broderbund); biofeedback and other sensor-linked software (HRM, "Integration," by Arcturus Arts).

* **Connection-Making and Association Games**. Synectics-style material (Gordon and Poze, 1967). Can be tied to writing (e.g., "Calliope," Thornburg/Innovision, 1986) or multi-media ("HyperCard," Apple Computer, 1987). Multimedia products, such as "The Time Machine" (CD/I-based product, The Record Group, in preparation).

* **Construction Kits**. "ThingLab" (Borning, 1978); Game X (Kahn, 1981); the "TRIP" system & Programming by Rehearsal (Gould & Finzer, 1984); Smalltalk Simulation Kit (Goldberg, 1979); "Rocky's Boots" (The Learning Co.); "Lode Runner" (Broderbund), "Music Construction Set" (Electronic Arts), "The Factory" (Sunburst).

* **Cooperative Learning**. Multiple players and roles using the same piece of software. "The Other Side" (Tom Snyder Productions)

Creativity Tools. "Dazzle Draw", "Animate", "Print Shop" (Broderbund), "Fire Organ" (Vagabond Software).

Detective Mysteries. Interactive versions of Sherlock Holmes and Agatha Christie. "Tales of Adventure" (Scholastic), "Where in the World (USA) is Carmen Sandiego?" (Broderbund).

Dialogues. Interactive writing, stories, poems; over 100 interactive programs in poetry and the work of e.e. cummings, developed at Stanford University and the Stanford Research Institute (SRI); "Teaching wisdom" -- "MOSAIC" (Brown and Kahn, 1981); Socratic/inquiry prgrams on geography and weather (Collins & Stevens, 1983).

Early Childhood. Directionality, color, letter, number identification, "Juggle's Rainbow" and "Gertrude's Secrets" (The Learning Company).

* **Epic Adventure**. Find hidden treasure, use maps and subtle clues, "King's Quest" (Sierra On-Line)

Grid Game. Uncover objects in coordinate spaces "battleship," "Bumble Games" (The Learning Co.)

* **Videodisks**. Both interactive activities and visual archives: "The First National Kidisc," "The National Gallery of Art" (Voyager Press), "Principles of Biology" (Optical Data Corp).

* **Interactive video/software + television/multi-media combinations**. "The TheaterGame" (Stanford University/Academic Courseware Exchange), "The Voyage of the Mimi" (Bank Street College / Holt Rinehart and Winston), "Adventures in Mathland" (Mindscape, Inc.).

Jigsaw Puzzles. Especially for early childhood; includes picture completion and tangrams.

Laboratory Simulation. Chemical reactions, titration, nuclear reactor simulation (e.g., "Scram," Atari, 1981).

Microworlds. "Programmable environments"; LOGO (Lawler, 1984, Papert, 1980).

Process Simulation. Run a business, coordinate a nation's energy policy, explore the West ("Oregon Trail," MECC, 1987); build the first trans-continental railroad ("The Golden Spike," National Geographic Society, 1987)

* **Role-playing & Social Games**. Dungeons and Dragons, run a kingdom, "Balance of Power" (Mindscape); "Life".

* **Space/Time Zoom**. Travel backward and forward in both historical time and place; for example, live in the Amazon in the year 1200. Models are "Cosmic Zoom" (film by Joe Koenig, Canadian Film Board), "Powers of Ten" (Scientific American Library and the Studio of Charles and Ray Eames), "The Would-Be Gentleman" (Stanford

University/Academic Courseware Exchange).

*** Telecommunications and Network-Based Programs/Projects**. National Geographic Society / TERC "Kids Network" (Tinker, 1987); "Earth Lab" (Bank Street College of Education).

Tutorials. Interactive lectures (including embedded "coaches," e.g., J.S. Brown, et al., 1975) of virtually all subjects and complex skills; especially common in higher education and adult (corporate) training.

Trivia. Fun questions tied to beating the clock, a car race, tug-of-war

Writing and Word Games. Anagrams, crosswords, computer-assisted stories. "Story Tree" (Scholastic) and "Bank Street Writer" (Broderbund/ Scholastic), the "Explore-A-Story" series (D.C. Heath / Learningways); "Reader Rabbit" (The Learning Company); "CompuPoem" (S. Marcus, 1984).

Note: We feel that these categories (*) hold special promise for continued innovative development, partially due to recent cost reductions in optical storage media, such as CD-ROM, and some due to wider access to low-cost telephone networks and modems for computer telecommunications.

The Next Five Years

From the time of its beginnings, developments in computing have sustained a continuous, dramatic improvement in price performance. The machinery gets smaller, cheaper, and more capable year by year. At the same time we grow to understand it more, more useful good and bad examples emerge, and public access and acceptance increase. In the next five years, we will enjoy megabytes of memory, high-speed execution, many- colored displays, and high-performance software at prices easily under $500, and probably some competent systems at under $100. Already, many educational software publishers have introduced lines of $10 software (e.g., Mindscape, Disney, ShareData), and the public-domain libraries, such as SoftSwap (Computer Using Educators) in California, will continue to grow forever. In fact, many of the best-selling computer education books are collections of simple, demonstration programs which span a variety of educational teaching styles and applications.

Several hundred excellent educational software products have now been produced, and the number may double in the next five years. Such products include not only microcomputer programs for Apples, IBM PCs, Tandys, Ataris, Amigas, and Commodores, but also a growing number of interactive videotapes, laser disks, and multi-media packages.

The future in education, as in the past, will not be marked with abrupt changes. Rather gradual, organic progress will occur on all fronts, integrating and blending the technology into the normal school process. The best of it will be unnoticed, a natural adjunct of daily teaching.

Expect better authoring tools and systems, permitting more students and teachers to create software, according to their own local needs (Zauderer, 1987). Better graphics and animation tools will allow more people to augment the richness of the interactions (e.g., "Dazzle Draw" and "Animate" by Broderbund, Inc). More models of exemplary software will show developers how to use more imaginative modes of presentation, and increase the demands of the teachers. Deeper insights from the cognitive scientists on the characteristics of good teachers (Collins & Stevens, 1983) and how people learn will be applied to expand the stable of teaching algorithms.

In hardware, expect more of what we now have, with more features (e.g., color, sound generation, memory), faster performance, and at ever-decreasing costs. There will be hand-held computers in the $50 cost range, dedicated to particular topics. Credit-card sized storage media, such as Drexler's LaserCard(tm), with many megabytes of data, and costing about $1 apiece in large quantities, are already in preliminary use in educational, medical and insurance fields. Here, as in software, hardware design should be guided by the unfolding science of the learning process.

Interactive laser disk players of one sort or another now cost no more than most common educational microcomputers and provide up to 54,000 individually addressable images on one side of a 12" optically read disk. In sufficient quantities, such disks can be produced for well under $10 apiece. Laser disks are already being coupled to small computers to provide high-speed interactive graphics responses and embellishments to the student's flow of thought. Especially promising research in the effectiveness of merging computers and interactive videodisk is already being found in many areas, e.g., language learning for young children (Miller & Gildea, 1987).

Since an element of laser disk memory can consist of sound tracks, single frames of slides or artwork, animations, "film strip" sequences, or video clips, we can imagine the richness of interaction that is now available. The extremely high popularity of the laser-based, digital compact audio disk (CD) will be extended to incorporate both still frame and full-motion video, as well as storing very large masses of data. Names for these applications include: CD ROM (Lambert and Ropiequet, 1986), CD/I (Lambert and Sallis, 1987), and DV/I (GE/RCA/SRI Sarnoff Research Labs, 1987).

Furthermore, video cameras will be used more and more as input devices, with powerful dedicated graphics microprocessors allowing digital capture and manipulation of graphics images in real time. This combination will allow unprecedented feedback of facial expressions and body gestures as an integral part of educational programs for children's learning, adult training, and recreation for people of all ages. The merging of tomorrow's microcomputers, video input and output technologies, and the ability to browse associatively through large mult-media data bases promises to bring educational technology into major new areas for innovative development.

Government and corporate-funded efforts in multimedia, especially computer-videodisk combinations (Apple Computer, 1986) and continued research into advanced human-machine interfaces (Foley, 1987; Bolt, 1984) will propel educational technology into the next decade as an important adjunct to "full spectrum learning" (Apple Computer, 1987). Continued excellence in development of products which contain elements of high quality educational television, computer interaction, and ultimately, videodisk, will become commonplace during the next five years.

"Megatrends"

In examining historical developments and analyzing current research and development efforts, we have found ten major trends which we feel will continue to influence (or inhibit) innovation in development of educational technology's full potential. We refer to these as "megatrends" because they do not depend on any single area of hardware or software development, but rather on the *gestalt* created by blending the talents of creative individuals with the new technology:

(1) Computer systems are augmentations of the human nervous system.

This metaphor, which is at the basis of early cybernetics and cognitive science research, continues to gain wider acceptance. It is reflected in new architectures for computers, such as parallel processing machines and mass distributed processors. It is also at the basis of viewing the entire body--the eyes, hands, ears, and ultimately, all the senses--as components of the human-machine interaction. Furthermore, as recent software products such as Apple's "HyperCard" suggest, this metaphor should be well understood by both developers and teachers, as it will refocus attention more on the processes of thinking and less on specific content.

Implications of this metaphor may already be found in the large variety of input devices available for interaction with microprocessor-based products, both for normal and exceptional learners. The integration of voice (both simple activation and some speech recognition), gesture, high quality audiovisual output, and other modalities will encourage the movement for educational technology to engage "full spectrum learning" (Apple, 1987).

(2) Hardware capability and speed will continue to increase, while size and cost decrease dramatically.

Microprocessors--and now microcomputers-- are such a ubiquitous technology that most people are not even aware of their existence in products used every day in business and industry, schools, and homes. The standard simultaneous increase of computer power and decrease of cost over a decade of time has continued for several decades. In the video and digital audio (CD) areas, drops in price have been even more dramatic.

Developers and publishers will always have to face a standard dilemma in this domain: Hesitation to venture into new, more powerful systems because of investment and previous training on older, but proven, technologies. The solution to this dilemma in education is *evolution*, not revolution.

(3) Educational technology products will increasingly involve more and more multi-media and multi-sensory elements.

Diverse media have been gradually converging into a common digital form. Two major catalysts have been the popularity of compact audio disks (CD) and a renewed interest in optical storage media, beginning with the laser videodisk and more recently, CD-ROM technology. Software, film, 35mm slides, audio, video, full text, compressed speech technology, and printed media may now all appear as components of integrated learning environments.

As stated above, this powerful combination of multi-media also poses considerable challenges to the developer and learner (Apple, 1987). More research and development must now focus on the issue of browsing--i.e., how people find exactly what they're seeking, or more importantly, what they really *want*--from enormous quantities of information in these different media. It is in this domain that cognitive science and research on incidental and informal learning will be of increasing value (Rosenfeld, Ibid.).

Educational products combining the use of microcomputer software with videodisc, CD-ROM, and other media will become more prevalent as the cost of these media decreases. As exemplary multi-media products begin to appear, administrators will become aware of the immense educational potential of multi-media experiences, and schools will begin to purchase the necessary hardware.

With the rise in availability (and decrease in cost) of innovative input and output devices, senses other than sight and hearing will become central to educational technology products. "Gesture gloves" with tactile feedback and head-mounted, three-dimensional displays (Foley 1987) will be affordable to the consumer within a few years.

(4) Telecommunications is being incorporated into more and more educational technology applications.

Marshall McLuhan's notion of a "global village" is becoming more of a reality due to the rapid growth of computer networks (R. Kahn, 1987). Rapid global access to information is now available through such projects as the ARPANet, IBM's "Bitnet," and the recent "Kids Network" for scientific research, an NSF-funded project being developed by Technical Education Resources Center (TERC) in Camridge, MA, and the National Geographic Society.

First developed by the technologies of the telephone, radio and television, the idea of "global village" multi-media networks now allow for interactions between people of all ages, cultures, and geographic locations, in groups or as individuals, at any time of the day or night. Teleconferences, such as those of CONFER at the University of Michigan, have allowed people with similar interests to carry on conversations with others over prolonged periods of time. This same technology is also encouraging more collaborative educational software with people from different geogrpahic locations or ethnic backgrounds. Bilingual interactive games, for example were demonstrated between Spanish and English-speaking children over five years ago (Picodyne, 1982).

(5) Increasing attention is being given to determining what constitutes "exemplary" educational technology products.

Innovation in educational technology depends upon developers having examples of what parents, teachers, students, and publishers feel to be outstanding products.

Rather than trying to find a universal list of what are considered to be the best products, we should expect strong differences of opinion in this area. Educational software reflects pedagogical style and philosophy of its authors and designers, and we should encourage diverisity of approaches. A Darwinian process will continue to separate out the best products and their later successors.

However, educational developers can benefit from continuing research and dialogue about this crucial issue. It is important for there to be extensive sharing and dissemination of opinions and research findings in this area which can produce a set of design "guidelines" or principles for continuing to advance the state of the development art.

Parents and educators will become more vocal and organized in their quest for program recommendations and design standards. Developers will have to meet these design standards if their products are to be accepted and purchased by an increasingly well-educated audience.

There will be increased emphasis on software that encourages insight, invention, and creativity. "Microworlds" (Lawler, 1984), (Papert, 1980), "simulations", and "directed exploration environments" (Zauderer, 1987) will encourage active, discovery learning (Massialas, 1983), (Henson, 1980) and practical involvement in explorable domains. Software will move away from CAI, and will allow students to play an active role in their own learning, thus shifting the focus from the computer to the child.

A high value will be placed on software that facilitates and encourages cooperative learning. As Johnson (1985) notes, teachers often have groups of 2-4 students participate in cooperative learning exercises. More importantly, although 93.6% of U.S. public schools now use computers in education (QED, 1987), the ratio of children to computers still stands at about 50:1 (Ploch, 1986). As such, it is often necessary for students to collaborate in using the computer.

An increasing amount of software will be "machine-independent". With the wide variety of microcomputers available for the classroom and the home, children, teachers, and parents will wish to be able to use these machines interchangeably, and will wish to share information between similar programs. Bill Atkinson, developer of Apple Computer's "HyperCard" authoring tool, sees a "worldwide sharing of information" in which there are HyperCard-compatible programs on all machines. As such, he is revealing key details of HyperCard's structure to other developers (Goodman, 1987).

(6) There is a movement toward more involvement by educators and students in developing, testing, and refining educational technology products.

This trend accompanies a larger (and older) historical trend away from limited access to highly centralized, tightly controlled volumes of data towards local community control and individual access to information. Decentralized information access and distribution affects everything from running a business to desktop publishing. This same movement affects all media, from neighborhood cable television to personal portable reference libraries on CD-ROM or pocket Drexler LaserCard(tm).

In providing teachers and students better authoring systems and tools (see Appendix II), more and more people will be capable of providing educational programs. As was cited above, students may become one of the best untapped resources for developing their own educational programs, and in the process, learning far more about a given topic. This trend follows a movement toward more peer teaching from the late 60s, one in which peers may now be somewhere around the globe.

More developers will realize that educational expertise is critical to the design of high-quality educational software. As such, developers will recruit more educators for the "teams of experts" that design the software.

Through built-in or independent "authoring tools" (Zauderer, 1987), teachers will begin to tailor educational software for their students. "Teams of experts" can be an effective means for designing and developing educational software, but communication amongst team members can become problematic. A typical "courseware production team", as Kearsley (1986) notes, involves eight people: an instructional designer, a subject-matter expert, a programmer, a graphics designer, a script writer, an editor, a project manager, and an evaluation specialist. This can result in jumbled communcation and misunderstood responsibilities.

Rather than asking educators to build software from scratch, developers will provide them with powerful authoring tools and/or rich, easily customizable, computer-based learning environments. These systems must be far easier to use, and far more complete in their support for educational computing, than either introductory programming languages or traditional authoring tools (see Appendix II). Educators will be provided with exemplary educational software which, if necessary, can be customized for a class or a student with a minimum of effort.

Educators will seek training in educational computing, through in-service workshops, seminars, community college classes, and university classes. In addition, federally-funded "Centers of Excellence" will foster learning and discussion amongst educators, developers, researchers, publishers, and parents.

Future Authoring Tools. Several trends will influence the design and development of the authoring tools of the 1990's.

- Multi-media Integration. Authoring tools will become better integrated with videodisc, CD-ROM, and other new storage media. As the cost of these new media decreases, their potential for education will become more apparent to educators, parents, developers, and consumers. As such, providing a easily accessible means for tapping that potential will become critical.

- Specialization. The authoring tools of the 1960's and early 1970's were general: each tool was meant to facilitate the creation of a wide variety of instructional programs. In the late 1970's and 1980's, tools became more specialized. As mentioned above, the "Alternate Reality Kit" is especially suited for the creation of physical simulations. "Course of Action" works well for computer-based training. "HyperCard" allows for the development of linked networks of multi-media information. Because of the increasingly specialized needs of educators, the authoring tools of the 1990's will become more focused on particular metaphors or interaction styles.

- Analysis vs. Synthesis. Most traditional authoring systems facilitate "synthetic" creation of software: the author uses the system's tools and elements to create software quickly and effectively, "from the bottom up". This style of authoring will continue to be popular in the 1990's, but another, more analytic style will become popular as well. In this approach, educators will construct software by examining, understanding, and customizing applications inherent in the tool itself. In this way, the distinction between authoring tools and educational software will be blurred; a means for customization will be embedded into educational software products.

(7) The contributions of cognitive science to understanding the "structure of knowledge" are being balanced by a need to better understand the domains of affect and motivation.

Major NSF- and military-funded efforts in the field of Intelligent CAI (ICAI) have been underway for over a decade. Pioneering work in this area is now taking place at many research institutes all over the country, including: Bolt Beranek & Newman, University of Pittsburgh, Carnegie-Mellon University, New York University, University of California (both Berkeley and San Diego), Xerox Palo Alto Research Center, etc. These efforts are an attempt to map new understandings about mental processes into the development of interactive teaching materials.

Over the last three decades, psychology has undergone a major paradigm shift from a mechanistic, behavioral conditioning model of human performance towards an interdisciplinary "cognitive science," including artificial intelligence, linguistics, anthropology, epistemology, and neurophysiology. With this shift has come renewed attention to the importance of educational development of and understanding of higher-level thinking and problem-solving abilities. Similarly, atttempts to understand the cognitive characteristics of interactive teaching (Collins & Stevens, 1983) will lead to qualitative improvements in the development process.

At the same time, the affective and social dimensions of learning, especially in the areas of intrinsic motivation, self-worth, and personal values, have taken even more importance than before. Work on understanding the affective domain of educational technology (Brown, et al.,1969), attributes of success and failure in school settings (Covington & Beery, 1976), dimensions of intrinsic motivation (Lepper & Greene (1977) and Malone (1980) is as important now as ever.

(8) "Repurposing" of older high quality educational material with the new educational technology will maximize past investments.

Major curriculum development efforts of the 1960's -- many of them federally funded -- are experiencing new life when merged with microcomputers, interactive video, and telecommunications technologies. Furthermore, because of the various factors mentioned here, the traditional roles of "teacher" and "student" are undergoing subtle, but important changes. Teachers are becoming both facilitators and resources, as opposed to subject matter experts, and students are becoming authors or designers of their own educational experiences, as well as research collaborators.

(9) Educational technology is being applied to learners of all ages in a wide variety of learning environments.

Lifelong learning, adult basic education and professional development, cultural literacy, enrichment for exceptional people (including the gifted, handicapped, economically disadvantaged, and senior citizens) are now placing schools in a more reasonable overall educational context. Similarly, the importance of supporting and improving community informal learning institutions, such as libraries, museums, clubs and youth groups, and community centers is being felt at all levels (AAM, 1983; Rosenfeld, Ibid; R. Kahn, 1977).

As microprocessors are becoming commonplace in consumer devices, educational software is becoming ubiquitous. Microwave ovens, washing machines, and toys are becoming increasingly technology-oriented, and thus often require "on-line" instruction or guidance for proper use. In addition to the home, educational software will (or already does) appear in such places as airline waiting rooms, hospitals & clinics, executive seminars, and leisure locations.

(10) Teacher accountability to standards will continue to drive or inhibit innovation in educational technology.

The issue of "accountability" continues to both inhibit and drive development of the potential of educational technology. Statewide and national standardized testing programs affect all levels of education, from the individual teacher to the publisher of textbooks and interactive media. Depending upon one's philosophy and perspective of education, this issue may be viewed as either an opportunity for development of large-scale educational programs or an inhibitory force preventing innovation.

Patterns of Diffusion of Innovation

Having briefly reviewed the history of development in educational technology and having extracted a number of trends for the future, a simple but cogent question remains: With all of the advances in human interface research, better authoring tools and teaching algorithms, and knowledge about what constitutes exemplary products, what factors promote or inhibit the development and effective use of innovative educational technology products?

There are many ways to answer this question, some which are specifically related to the nature of the formal education and some which are generalizable to any innovation. For example,publishers of educational products must be able to anticipate an adequate return on investment in order to take risks in developing products which are clearly exemplary, but which may be difficult to sell in a current market. One developer stated that the average development cost for a single educational software product was between $25,000-$35,000, and that this estimate was for the simplest "drill and practice" products. The cost of development of far more interesting products (such as simulations or "construction kits") is almost always higher than this by a factor of at least two or three (Hakansson, 1987). Another developer added that investors expected sufficient financial returns on development costs over very short periods -- for example, one to two years. This financial model often leaves the developer in a double-bind: On the one hand, the developer knows the kind of product which would embody the high-quality criteria and expertise gained from years of experience; on the other hand, commercial publushers funding such innovative products are asking for returns on such products over far too short a time span, especially in the school market. A more reasonable model would project such returns over at least a 3-5 year time span (Zawolko, 1987). It is for this dilemma that joint ventures, such as the recent California Software Development Partnerships program or federal support of innovative technology-based curricula (e.g., NSF, Office of Special Education) are vital to continued innovation in educational technology.

Another answer to this question requires looking at the general process of innovation. The standard model of "diffusion of innovation" (Drucker, 1985) posits that early markets for innovative products are populated with "innovators." Thus, the first users of innovative educational technology products are most likely to be the developers of such products themsleves or those who see themselves as open to change, newness, and creativity. For this small population, price and "user-friendliness" are not usually the primary driving force.

Innovators then influence others, known as "early adopters," to purchase the innovation. This wave is then followed by the "early majority," the "late majority," and finally, "laggards." As followers begin to take more and more share of the user population, their values tend to shift from performance *per se*, to price and user-friendliness or utility.

Thus, as the marekt matures, different values begin to dominate because those "majorities" adopting the innovation have different values than the "innovators" who led the way. In terms of educational technology, this model may explain why once a particular metaphor of using computers for education has enjoyed a some success (e.g., "drill and practice"), it becomes difficult to introduce alternative or new software "metaphors," except to the small population of innovators and early adopters. Thus, success of certain products deemed innovative in their own time frame may actually inhibit new innovations even more strongly than if no innovation had taken root at all.

A standard progression of "stages" of use of computers in schools shows a developmental approach to a diffusion model of increasing use of computers in the classroom. While this model may, at first glance, be very disconcerting to developers and publishers, it may also be seen as an opportunity for improving the acceptance of more innovative products over a longer time span (Bradsher, 1987):

(1) Typically, a single teacher (often the math teacher) is the "innovator," able to acquire funds for purchasing a number of computers through federal or state capital

funds (separate from those for books or other audio-visual materials). This teacher then tends to control the use of the computers.

(2) If the principal wants the use of technology to spread, he or she must set up teacher training programs for teachers in other subject areas; however, computer use for these other teachers is limited, since most of the school's software is for the teacher who acquired the computers (e.g., math).

(3) The spread of the use of the computers most often comes when other teachers discover there is "drill and practice" software for their subjects, software which requires almost no extra time or training of the teacher. The use of this software, however limited it may be, frees the new "computer using teacher" to work other kids needing less remedial assistance or practice.

(4) Then, one or more teachers discover word processing. This application is clearly benficial to both students and faculty alike, but to be used effectively, it requires a large number of computers. The purchase of additional machines is justified because "writing" is such a basic skill where computers can make a clear difference in students' work.

(5) For the diffusion to spread further into other subjects and applications, the driving or inhibiting force seems to be whether or not the interested teacher has a computer of his or her own at home. If the teacher is a computer owner, then routine administrative tasks (letter writing, grading, reports, etc.) can be made more effective--i.e., the computer is used as a productivity tool. This personal use then paves the way for instructional applications, since there is little resistance to the technology itself.

(6) Collaborative use can grow from several of the above stages--word processing, personal teacher productivity, etc. often leads to using the computer to generate, edit and produce a school newspaper, using software such as "The Newsroom" (Springboard) or "Print Shop" (Broderbund). Here, clearly a lot of students can be

involved in all the various facets of such a project, and a great deal of excitement and intrinsic motivation is involved (note that this is usually an extracurricular activity).

(7) Finally, science teachers--a group one would think of as innovators or early adopters--but in fact are usually among the last teachers to use computers for instruction--want more "hands-on," discovery oriented materials for thier classrooms. Laboratory budgets have been severely cut over the years, and they discover that computers can be used as "probes" for real-time measurement in science experiments. TERC (Technical Education Research Centers), funded by the National Science Foundation and private industry, has pioneered this concept for almost a decade and now has an avid following of over 35,000 teachers nationwide. Not only is software and hardware made available, but a support newsletter helps show how different teachers integrate the microcomputer based laboratory (also known as "probeware") into their classroom. In this application, the computer keeps track of data which is dynamically changing, and thus, it is not a vehicle of "direct instruction," per se (Tinker, 1987, 1985).

Policy Options

It is clear from the history of development and from analysis of current trends that educational technology, when carefully matched to the needs of students and teachers, has enormous potential for improving education. Many exciting new developments are happening every day, in learning environments including the home, classroom, library, museum, and the workplace. Yet, we hear all too often about our country's mass problems of functional illiteracy (both in children and adults), students' lack of basic skills and conceptual knowledge in the humanities, and the universal desire to improve our ability to think critically and productively in solving personal, local, and (inter)national problems.

How can the government help make the best use of educational technology's potential? Policy options are derived from educational needs and from technological possibilities. Within the social context, we need equal access to educational opportunity for all. We are committed to retain and cultivate the valuable heterogeneity of our culture, to use technology to make educational resources available to many people, and to build bridges between sub-cultures. We can prevent a world of educated elite from diverging from those among us who are still deprived of learning. We can use technology for more than standardized education to produce standardized people. We can aim for a society where all of us have more than mastered the basics of creativity and individuality, where we are equipped for the necessities of innovation, efficiency, comfort, and style -- at all levels, ages, and subcultures. Ultimately literacy, cultural literacy, is the indispensable investment required for success.

These social objectives are met by attending to the individual student, in the classroom, at home, in the hands of good teachers (which is to say, the teachers of the moment, doing their best and laboring under the circumstances).

With these goals clearly in mind, technologists can devote their efforts to the fundamental issues. Innovation in educational technology is the result of a successful multiple partnership which includes: local, state, and federal agencies; private funding sources; publishers, developers, researchers, teachers, parents, kids, employers and employees.

The past thirty years have already contributed a great deal of knowledge and experience to our ability to use interactive technology wisely in education. It is now time to make a major long-term strategic investment, one which can succeed in providing a qualitative improvement in our nation's education of coming generations. Our recommended areas for support are thus those where we feel large payoffs are needed and where substantial contributions can be expected.

Beyond the Classroom

In applying educational technology R&D, we need to expand the "learner" to include:

Lifelong Learning

Growing from 24 million retirees in 1960 to 41 million in 1986, we now have a robust appetite for enrichment and leisure educational software on home computers interconnected with VCRs and educational television. Also, the need for continual training and education in corporations continues to grow more and more each year.

We need to break out of thinking of life as three separate, but mutually exclusive "boxes"-- education, work, and leisure--and move into more integrated, interdisciplinary ways of thinking, learning, working, and playing (Bolles, 1978; Caspi, 1987).

Support for this perspective is not likely to come from the traditional individual sources of funding for educational technology. Coordination and cooperation will be needed between agencies as diverse as The Departments of Commerce, Labor, and Education; National Science Foundation; National Institutes of Health; and National Endowment for the Humanities. The payoff will be a rich, interdisciplinary approach to becoming a "learning society."

Basic Education

There are 35 million "functionally illiterate" adults in this country -- approximately one fifth of America's adult population (Bradley, 1987). Of these, only approximately 4 percent currently get remedial education.

In this regard, IBM has recently developed the "Principles of the Alphabet Literacy System" (PALS), and the Department of Labor is providing small, but important support of several projects using interactive technology to help remedy this problem in the workplace (The Videodisc Monitor, Aug., 1987).. Note that these efforts are being funded outside of traditional educational technology R&D support channels.

Furthermore, 3.1 million adults each year go back to school. Many of them are women or people from poverty levels, wishing to obtain credentials for improving their employment status.

Thus, support is clearly needed for development of "Basic Survival Skills." Software in this area should execute on the lowest-cost range of equipment. Its development would be a social boon as well as a technical challenge.

"Exceptional People"

This means the handicapped, gifted, peculiar out-of-the-norm people of any age who aren't served by the convential educational process. This group comprises a broad array of challenges for unusual hardware and software re-design and re-configuration. We are all both specially gifted with unique constellations of abilties, as well as handicapped by some mental or physical limitations; thus, focussing on the "exceptional learner" will result in improving all learners.

Accountability

There is a trend toward federal standards, or guidelines, for teachers and school systems. Among other factors, this could be used as an indicator for evaluating funding programs. A set of software constructed in conformity with these educational criteria would give every person and every school system, regardless of locale, a chance to study to the "national standard". In addition to the written standards, the schools would have interactive lesson material to help attain them.

Action Research

Creation and support of a national network of interdisciplinary "Educational Technology Centers of Excellence."

In conjunction with local schools, museums, universities, and corporations, these centers will serve as demonstration, development, and dissemination centers for exemplary educational technology projects. They will also serve as major "action research" and training centers for teachers, eductors, researchers, and other professionals involved in the development of educational technology. These centers will house libraries of examples of past and present exemplary technologies and products, including "spinoff" technologies whose original development was not tied to education, and will encourage cross fertilization from the arts, humanities, and sciences to educational technology through conferences and development projects.

Such centers should be tied to a variety of formal and informal learning institutions in each community and should provide an environment in which professional developers, educators, and students can collaborate on innovative projects. One of the main goals of such centers should be the professional development and training of oustanding talent in educational technology, both in the public and private sector. Thus, these centers must be collaborative efforts, linking universities, schools, software and hardware companies, and publishers. Successful models for such centers include: The Smithsonian Institution's new Center for Interactive Media in Washington; Education Development Center in Newton, MA; Technical Education Research Centers (TERC) in Cambridge, MA; the EQUALS and other action research projects at the University of California's Lawrence Hall of Science, Berkeley; and Bank Street College of Education in New York.

Greater research and development efforts on integrating technology into both existing school curricula and "informal learning" environments

Informal learning environments (such as homes, museums, community and senior centers, and extra-curricular youth groups) provide an excellent source for both interdisciplinary development and testing of innovative approaches to learning. Furthermore, a renewed emphasis must be placed on the use of interactive media in conjunction with "hands-on," multi-sensory approaches to learning in order for this technology to reach its full potential. The link between the community and the school may then be made for learners of all ages.

Basic and applied research in the areas of the psychology of intrinsic motivation, self-esteem, and personality and social factors of learning.

In order to encourage development of a complete "education science," these important areas of education -- especially the whole field of self-directed education -- need to complement current research emphasis in cognitive science.

Cooperative industry/government-supported training programs for professionals in educational technology development.

The growth in better tools for "authoring" is resulting in expanding the field of potential developers of interactive technology products. More exchange of experience is needed between educators, professional developers of educational technology, teachers, researchers, authors (subject matter specialists), artists, parents, and others whose full-time occupation is not necessarily the development of commercial products, as well as implementation training and follow-up support for both formal and informal learning environments.

Development and dissemination of standards and criteria for exemplary products.

By this, we do not necessarily support the adoption of a single, universal set of standards for excellence or innovation. Rather, we are recommending encouraging diversity, rather than uniformity. However, we wish to strongly encourage dialogue about guidelines for maintaining the highest quality in educational product development while also addressing both local, state, and national testing (certification) requirements for all levels of education and training.

When these areas are considered in more detail, virtually every major issue in education can be seen to fit in, in such a way, in fact, that technology can contribute.

In closing, as a top priority, we urge the federal government to make a strong statement about the importance of improving education as the foundation of our nation's future. This should be done in a number of ways, including joint partnerships with industry and state and local governments. The building up of a stably funded, long term action research agenda designed to make a substantial impact on education can begin through establishment of a network of Educational Technology Centers of Excellence. These centers should focus their work on educational issues requiring top level research, development, and demonstration projects in which educational technology is likely to provide a key for innovative results. The Centers should also support large libraries of exemplary products, machine environments for testing various psychological and pedagogical concepts, and training facilities for teachers and students to convey the innovations to schools, homes, and commerce.

Glossary

AUTHORING SYSTEM: A combination of hardware and software designed to allow non-programmers--especially teachers, authors (content experts), and students--to design prototype interactive educational products and to edit such prototypes into running lessons, modules, or products.

BIOFEEDBACK DEVICE: Any one of a number of input devices in which direct electrical measurement of the body's output (e.g., skin temperature or Galvanic Skin Response (GSR) can be used as input for program control. A number of programs based on use of such devices for relaxation, stress management, and mental concentration are now available as consumer products. Using biofeedback is a method of accessing subconscious or unconscious knowledge and is most commonly known in "lie detector" tests.

BLOB MAP/MENU: Most computer menus are presented as a list of verbal or iconic options, displayed much in the same way as a restaurant menu. The video screen may be constructed so that the area of different regions is not only sensitive to user input, but that these areas also represent relationships which the user may pick up "incidentally" from the visual layout of the screen. Maps are a good example.

EYE TRACKING: When the eyes "see" a stimulus, the pupils qucikly scan the visual field in a number of quick jerky motions. Monitoring equipment called "eye trackers", such as those developed at SRI in the 1960s, can be used as input devices for computer program control, and are extremely accurate at picking up immediate reactions of the nervous system to visual stimuli.

GESTURE GLOVE: An input device in which the user may control a computer system or program by gesture in three-dimensional space, e.g., left/right, up/down, or in/out (towards/away from display screen). Both consumer and industrial versions are currently being produced by VPL Research in Redwood City, CA.

HUMAN FACTORS: The discipline that tries to optimize the relationship between technology and the human.

JOYSTICK: A common input device, originally based on the altitude flight control stick in an airplane. Made popular in many video games, joysticks allow a user to move (objects) on a video screen in order to select options or perform program functions in two-dimensional (X-Y) Cartesian space.

MENU: A form of output which allows a user to easily select from among a number of possible program options by using either single keystroke, cursor keys, joystick, or mouse. The main advantage of menus is that they reduce a user's memory requirements and decrease extensive typing or keyboard entry. Some forms include alphanumeric choices (keyboard or mouse entry), iconic (graphical symbols depicting different options), and maps (see "blob map").

MOUSE: An hand-held input control device, designed originally by Douglas Engelbart (1963) as part of an Air Force/ARPA project to develop computer augmentation systems for human performance. The mouse became well known during its ubiquitous use at Xerox PARC during the 1970s, and is now a standard control device for many common microcomputers, including Apple Macintosh and //GS, Atari 540ST & 1040ST, Commodore Amiga, and Microsoft's version for IBM PCs and compatible microcomputers.

PULL-DOWN MENU: A menu which is displayed only when needed, usually accessed by using a mouse to point to an appropriate command, icon, or screen location. The concept of pull-down menus keeps a user from having to look at too many options on a visual display at any time until they are needed.

SIMULATION: A computer program in which a user may act as if he or she is in situation which is not actually occurring at that time. Thus, a student may pretend to be an explorer in the 15th century or a scientist conducting an expensive experiment or a theoretician who wishes to see the result of violating a set of conditions or commonly accepted principles. This mode of computer interaction is widely accepted to be one of the most appropriate and powerful for developing critical and strategic thinking skills.

TUTORIAL: A genre of educational computer software in which a topic is broken down into a number of smaller, discrete units, each of which contains some ability to monitor a student's understanding of the topic and give appropriate feedback and direction as to how to proceed.

VISUAL PROGRAMMING LANGUAGE (VPL): A programming language in which programs are both specified and displayed graphically. For example, icons or symbols may be used to represent operations or program structures usually specified by strings of alphanumeric symbols.

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